UKTIN

Future Capability Paper

Wireless Networking

Executive Summary

Wireless Networking: Restoring the UK's Leadership

Wireless technology has revolutionised society, providing unparalleled mobility through devices like smartphones, tablets, laptops, and smart home gadgets. The Internet of Things (IoT) has further connected billions of devices, fostering a world of interconnectivity and automation across various sectors. From healthcare to transportation, education to entertainment, wireless innovation continues to shape our world, driving progress and improving our daily lives.

The United Kingdom has been a key player in wireless technology development, with significant contributions spanning over 150 years. Maxwell's work laid the foundation for radio science, leading to the first transatlantic wireless communication and radar development. UK engineers have been instrumental in the evolution of mobile standards from 2G to 5G, and ongoing innovations in small cells, semiconductors, and shared network technology showcase the nation's continued impact.

However, the past 15 years have witnessed a decline in the UK's investment and leadership in wireless technology. Global dominance by international vendors and reduced local R&D investment by some UK operators pose challenges. While UK university research remains world-leading, sub-scale involvement in the supply side of wireless networks risks diversity, security, and resilience, along with potential economic and skill losses. The UK Science and Technology Framework aims to reverse this trend, highlighting Future Telecoms, including wireless networks, as crucial for the nation's Science and Technology Superpower agenda.

This report contributes to achieving that goal. The UKTIN Wireless Networking Expert Working Group, comprising UK wireless ecosystem experts, has diligently worked through 2023. Analysing gaps and strengths in UK wireless networking capability, the group offers recommendations to restore and enhance the UK's leading role in wireless. Members, representing personal views, bring extensive experience to produce findings organised into the highlighted themes below.

Market Dynamics set the context for the UK's opportunities in wireless, providing a home market in which to test UK innovation and a foundation to build capability and expertise. The UK public wireless market is highly competitive with challenging economics, though this competitive intensity has driven innovation & costs down, notably via global-leading network and infrastructure sharing arrangements. However, public network performance lags behind other nations and the operator business case for high quality networks remains unclear. Meanwhile, the nature of a mobile network operator is changing due to virtualisation and value chain disaggregation, alongside the growth of private networks and wide area systems dedicated to specific applications.

The UK market has been innovative regarding sharing and shown commitment recently to early-stage research and development (R&D), but we often struggle to leverage our innovation both domestically and internationally, with a risk early R&D does not convert into commercial success and a lack of scale vendors limits UK export potential. Government, both national and local, needs to be the catalyst and an early adopter for high quality network deployment, and for continued action to improve the economics of the sector. Focus is needed on areas of likely success such as open networks along with support for early-stage growth required to achieve meaningful research and development and innovation (R&D&I) impact. Economic support is required to enable start-ups to grow into scale players for domestic and export markets.

The UK's research and innovation capability in wireless has a high global ranking in terms of research impact, but a relatively low ranking in terms of expenditure. The strength is derived from 25 universities active in wireless networking research, but lacks critical mass. Meanwhile, the UK ranks highly for investment in wireless networking start-ups, often spun out from universities, but fails to scale up small and medium-sized enterprises (SMEs), illustrating the challenges in jumping the gap from research to innovation and engagement with industry. We need to prioritise to incentivise for 6G research and innovation, while requiring impactful industry collaboration as a condition for 6G research funding provided to universities. A systematic approach to international collaboration will yield opportunities to promote UK research outcomes into global standards. UK operators should play a bigger role, for example by making network data on deployments, traffic, channel conditions, etc available to researchers, subject to the creation of an appropriate legal framework to support this.

Radio frequency (RF) technology is intrinsic to wireless communications, requiring specialist components and skills not found in any other area of technology. The UK has a rich history in RF and was for some time considered a global leader. After the telecoms boom and bust the landscape has changed significantly but much of the talent remains, now in the shape of several regional clusters creating a vibrant SME supply chain. The drive for supply chain diversification is a real opportunity to restore RF capability, but faces challenges in skills, international competition, the cost of market entry and the lack of a major domestic system integrator. Recommended actions to restore capability include facilitating low-cost access to test equipment, targeted Government procurement initiatives, a focused roadmap to leverage and commercialise existing academic excellence and a coherent drive on skills.

Semiconductors for baseband processing are another specialist area for wireless communications, embodying a high proportion of both the complexity and the value in wireless systems. There were multiple teams in UK-based industry in 2000s targeting a variety of platforms – while some pockets remain, targeted action in areas where the UK can lead will be necessary. Future trends leading towards 6G opportunities include targets for higher performance, improved energy efficiency, cell-free operation, wireless sensing and new compute paradigms for native-AI networks. The group recommends that targeted funding for wireless semiconductor development investment environment needs to be more conducive to Radio Access network (RAN) semiconductor development. Investment in artificial intelligence (AI) for wireless skills is needed and those with deep wireless expertise are good candidates to acquire those skills. The group also advocates the creation of large-scale field testing facilities for advanced capabilities to allow UK-based companies to mature and showcase product capabilities.

Standards and Intellectual Property (IP) are pivotal in facilitating global market access and preserving value in wireless systems. Despite the significant contributions of UK-based experts to top 50 5G and Wi-Fi standards-essential patents globally, no UK-headquartered company holds ownership. The UK lags behind in wireless networking patents compared to other countries. UK engineers lead in global pre-standards and standards-setting organisations, contributing to the industry's talent pool, however limited incentives, resources, and support hinder UK universities and small innovators from participating in IP creation and standardisation. The group proposes establishing a UK patent fund to incentivise filing, protecting, and pursuing patents owned by UK universities and small companies on favourable terms globally and domestically. A public-private partnership framework should connect UK academic and innovative institutions with the global industry for effective IP and standards collaboration. A strategic approach is needed to identify impactful and cost-effective standards groups for support.

Policy and Regulation shape the landscape of wireless deployment, impacting innovation both positively and negatively. The Government's recognition of Future Telecoms as a critical technology, encompassing all wireless technologies, beyond just 3GPP-based mobile, is commendable. This includes Wi-Fi, short-range, IoT, and private applications, offering accessible markets for UK companies. Wireless regulation is inherently international, with spectrum falling under the UN/ITU-R (International Telecommunications Union - Radio) framework. While the UK actively engages in global bodies like ITU-R and CEPT (European Conference of Postal and Telecommunications Administrations), Brexit has altered relations with European entities, posing challenges in influencing EU standards and accessing EU markets for SMEs. Regarding domestic regulation, Ofcom, our proactive independent spectrum regulator, fosters innovation through its spectrum sharing framework, which includes shared access licences across bands such as 3.8-4.2 GHz. Meanwhile, spectrum harmonisation is crucial for global markets but may hinder innovation. Encouraging experimentation and providing mechanisms for academia and companies to innovate in radio spectrum use is essential. Coordination with UK industry and consortia aids international influence. Leadership in evaluating the framework for shared mobile network codes and better-coordinated private network mobile country codes is vital for innovation in private and shared networks.

Skills and Talent are essential to rebuilding UK leadership in wireless and are no longer naturally built by the presence of large international firms with substantial R&D facilities in the UK. Academia creates a strong knowledge base, but without clear job pathways into the UK wireless industry this talent fails to gain the necessary experience and becomes lost to the sector. We need to identify lighthouse projects and companies, encourage and highlight them, and allow their halo effect to illuminate the wider telecoms industry. We also need to take a broad view of the relevant skills, with potential, for example, for Systems Integration and Infrastructure Provision skills to become UK strengths. Strong role models with diverse backgrounds are needed to help attract young people from all backgrounds into wireless. The potential for wireless networks to be an interesting target for newer skills, in areas such as AI and cloud computing, needs to be promoted alongside the overall public value of wireless. Industry also needs to be incentivised to support training schemes, fulfilling the role of industry sponsorship which previously formed a backbone for the pipeline of skills into UK industry.

Wireless research, development and innovation often rely on highly specialised and costly infrastructure and facilities, and good access to these can be a critical success factor. The UK has some excellent facilities in universities and commercial test labs, with particularly strong facilities in antenna and channel characterisation and satellite research. However, facilities for end-to-end network testing, and domains such as telco edge/cloud and security, are limited, and not all are easy to access by third-party researchers and companies. The group recommends the establishment of more comprehensive, end-to-end facilities representative of real-world network environments, with sustainable funding and updated continuously to represent the state-of-the-art and focused on helping high Technology Readiness Level (TRL) products and technologies make the transition into commercial reality.

Adoption: Given the existing strengths in UK wireless R&D&I, a crucial aspect is to focus on adoption of UK innovations into the marketplace. The limited number of large-scale end-to-end vendors for public mobile networks – none of which is UK-based – means channels to international markets are seriously restricted, and the incentives for UK operators to adopt locally born innovations are slim. Even when operators do show interest in local technologies, there is a long road to trial and integrate into operational networks. Remedies could include operator-held credits for adopting UK technologies into their commercial networks. Private, local and short-range wireless networks for special applications and IoT are already more diverse and may offer faster and less restricted opportunities for adoption.
In conclusion, while the UK has a proven history and vital intellectual and physical assets in wireless networking, sustained focus on these topics and implementation of the group's recommendations could help rebuild a world-class wireless supply base, reaping rewards as we move into the 6G era.

Summary of Recommendations

MARKET DYNAMICS AND ECONOMICS

- Government, both national and local, needs to be the catalyst for high quality network deployment: high quality wide area wireless networks are an imperative for both economic growth and societal development.
- The public sector should underwrite the deployment and availability of network capability which the private sector can then leverage to deliver significant economic benefit.
- Relentless regulatory and legislative focus is required to enable economic network deployment, with a clear remit to help create the conditions for building UK capability.
- The UK Government should ensure completion of activity which has already commenced, notably the review of annual licence fees and swift and effective enablement of the Product Security and Telecommunications Infrastructure (PSTI) legislation.

RESEARCH AND INNOVATION

Several of these recommendations follow those made by the UK Spectrum Policy Forum.

- The following areas are priority opportunities for UK Government to incentivise for 6G research and innovation:
    - Widespread wireless service coverage to prevent the manifestation of a “digital divide” and to contribute to improved health and social care outcomes and future transport ambitions.
    - Innovation in spectrum management (e.g. through the use of automation and AI), to improve spectrum efficiency and densify spectrum sharing, particularly in the low frequency, mid and mid high frequency bands suitable for mobile connectivity.
    - Economic viability of roll-out of next generation mobile infrastructure (through enabling new service possibilities or significant cost savings).
    - Alignment with the Government’s net zero targets.
    - Seamless connectivity – a “network of networks” (for example the integration of terrestrial and non-terrestrial networks) with high security and resilience.

- Participation in an approved "collaboration model" should be a condition of 6G research funding provided to universities.
- A systematic approach to the creation of more international collaborations like those led by DCMS (e.g. with the Republic of Korea and India) should be adopted and should target key partners, such as the USA.
- A managed and coordinated national approach is required to efficiently and effectively take the results of relevant UK 6G research projects into global standards bodies.
- Similar to the approach adopted by the 5G Open Innovation Lab in the USA, UK Government departments should partner with relevant and proactive innovation organisations on an occasional basis to create some cohorts targeted specifically at wireless networking.
- Incentivise UK operators to make data on network deployments, network traffic, channel conditions, etc available to researchers, subject to the creation of an appropriate legal framework to support this.
- Funding routes to be more obviously available to allow UK universities, startups and SMEs to push their research and innovations into large international organisations and operators.
- Universities should be encouraged to develop a multi-disciplinary approach to innovation in wireless networking, which includes software engineering, chip design, AI, business and commercialisation, for example.

RADIO FREQUENCY

- International collaboration. While UK companies may thrive in niche, high value elements of the supply chain, collaboration will be key to maximise the market opportunity and to embed UK content in future wireless systems.
- Low-cost access to test facilities. As previously mentioned, access to test facilities can be a significant barrier to new entrants to the market, although there are centres with relevant equipment these are often cost prohibitive to access. The best model seems to be to embed equipment within an industry setting with a core partner so the equipment is regularly used but remains open for access to others.
- Government procurement initiatives. Although not the largest buyer of telecoms infrastructure the UK still has significant spending power, which could potentially be used to convince suppliers to include UK supply chain into their networks. If successful this could lead to design into products that would then be sold in other territories.

- UK Strategy to cover multiple markets. For wireless technology and related semiconductors there is significant crossover from telecommunications requirements with those of defence and space, investments should be pooled and the roadmap developed so the UK has its sovereign needs met while maximising the commercial opportunities for the supply chain.
- Focussed UK roadmap leveraging UK academic base. Linked to above ensure the academic base buys into the same roadmap with a future looking perspective.
- Commercialising academic research. Once we have alignment between the academic and UK strategic roadmap the next issue to solve is the commercialisation of academic research, all too often the only option is a spin-out company which either fails due to lack of money or commercial acumen or quickly gets bought by large international companies. Could the Government invest to protect valuable IP then partner with the supply chain to take it to market? One model would be to recover the investment by licencing the IP.
- Coherent drive on skills. Here something needs to change as skills have been an issue for decades. Some combination of education and selling the industry combined with incentives (e.g. bursaries for students to study) may be a good combination.

BASEBAND/SEMICONDUCTOR ISSUES

- Advocate and support the upskilling of the existing base of those with deep baseband processing expertise in the field of AI.
- Support field trial access to trial innovative new techniques and demonstrate interoperability of AI techniques.
- Create an investment environment conducive to the funding business innovating in semiconductor compute devices for baseband processing in the RAN.

STANDARDS AND INTELLECTUAL PROPERTY

- A public-private partnership framework for intellectual property between the UK universities, research institutes, and smaller innovators, on one hand, and the global industry present in the UK and internationally on the other hand, is recommended.
- A UK fund should be created to support UK universities and SMEs in particular to apply for patents and help monetize these patents for example through licensing directly or indirectly (e.g. via patent pools).

- A network for individuals working for UK universities, SMEs and regional offices of international companies to collaborate in standards organisations should be created.
- A selective approach should be taken to determining standards groups which are both impactful and cost-effective to support.

POLICY AND REGULATION

- Ofcom, supported by UK Government, must continue the willingness to experiment, provide mechanisms for academia and companies to innovate in radio spectrum use.
- Ofcom, supported by UK Government, must coordinate with UK-based industry consortia and companies to keep influence channels open towards Brussels.
- The UK should lead in providing access to shared Mobile Network Codes (MNCs) and better coordinated private network Mobile Country Codes (MCCs) for private networks and UK neutral host companies.
- Extend the qualified expenses to R&D Tax Credits to patent filing and pursuit.
- Grants should be allocated on open calls which are rolling around a theme, adopting the approach used by DASA (Defence and Security Accelerator) without a specific application window.
- Government spending on setting up Intelligent Transport Systems (ITS) Infrastructure in the UK will help establish a lead in Connected and Automated Mobility solutions.

INFRASTRUCTURE AND FACILITIES

- To bridge the security and diverse interoperable system gaps, universities and research institutions need to collaborate with industry partners on real system deployment to share knowledge, develop practical solutions, and address real-world security challenges.
- While 5G test and trial projects offered valuable insights and in-depth exploration of 5G technology use cases and integration, a significant limitation is that many of these trials operated for a limited time, lacking the provision of sustained testing facilities. Therefore, there is a demand for permanent testbeds, akin to SONIC labs.
- The necessity for a security-focused Edge/Cloud interface underscores the importance of extensive academic research covering a spectrum from low to high Technology Readiness Levels (TRL) in the security perspective of 5G/6G networks. This involves bringing together interdisciplinary expertise for a comprehensive approach.

- A comprehensive testbed is required to facilitate full end-to-end technology integration, encompassing the 5G/6G communication environment, incorporating both satellite and terrestrial components. The diversity and distribution of funding to support expertise and facilities at different academic institutions are needed.

SKILLS AND TALENT

- Build on UK strengths and support industry
  - Celebrate small industrial kernels/hubs such as those fostered by major vendors and should be assisted in raising them to sustainable levels.
  - Encourage industry to re-ignite sponsorship and graduate programmes which have rarely seen by the current and coming generation.
  - Focus upon areas where UK strengths exist and deliver high value such as systems integration and infrastructure provision. Recognise the importance of AI as an increasingly important skill in wireless networking especially in the disaggregated RAN.
  - Develop shorter term wins, e.g. in commercial, capital and real-estate services, which are in strong demand by Communication Service Providers (CSP) and are very well represented in the UK and have a shorter path to success.
  - Bring high value IT techniques into the wireless networking curriculum.
- Promote, attract and retain
  - Develop strong, diverse role models to attract new talent and promote telecoms as an attractive career and as a sector bringing wider public value.
  - Incentivise industry training schemes, e.g. by offering credits to smaller companies.
  - Learn lessons from adjacent sectors to attract a more diverse talent pool, particularly before the older cohort is not available for skills transfer and mentoring. Engage the older generation, retaining them as consultants in order to use and transfer their talents beyond their expected retirements and loss of expertise.
  - Reduce the additional costs of postgraduate study via targeted repayments of student loans, and visa costs for example.
  - Set out clear options for telecom career pathways so that school leadership and careers advisors benefit from an applied appreciation of the routes available, including differences between direct industry entry, apprenticeships and postgraduate research.

ADOPTION/TRANSLATION

- The recommendations of the UK Government Wireless Infrastructure Strategy, and its Open RAN Principles, should be used to frame interventions that encourage adoption of new innovations, extending current programmes.
- The constraints placed upon dual use of results funded by civil research programmes may benefit from review. The group feels this would encourage innovation in other areas.
- Open RAN should be fully embraced as an opportunity for good, applied (high TRL) R&D as there are a good range of companies in the UK with relevant skills and ORAN should increase the opportunity to concentrate on a single element vs an end -to -end system. Also, it is more AI and software dependent so it is easier to grow than hardware dominant companies. This could be built on for 6G.
- Greater alignment between university research and facilities and industry could be assisted by "spin-in" companies, which conduct engineering development and testing in the universities and those universities should also have engineers dedicated to mentoring, testing and support of those companies, independent from their own research. Some universities already apply such a model but this could be more consistently applied as an example of best practice.
- The Government aspirations for UK involvement in 6G are welcome, but imply very near-term action on supporting companies to intersect with 6G standardisation and launch timescales.
- There should be incentives for universities based on implementation and impact dependent on financial output. A national funding pool to top up university funds for research would help.
- There is a need and opportunity for UK network operators and deployers to play a bigger role in ensuring a pull-through of UK innovation into UK networks, bringing operator benefits of early innovation and innovators benefits of a credible lighthouse deployment. One approach would be to grant operators credits in the form of tax credits or direct funding for qualifying adoption of UK-born technology into their commercial networks.
- Given the challenges of addressing public mobile markets, we should fully explore and support the potential for adoption routes via private, local and short range wireless networks for special applications and IoT, which are already more diverse and may offer faster and less restricted opportunities for adoption.

Table of Contents

Introduction, Scope and Contents

1. This Expert Working Group (EWG) of UKTIN was assembled following an open call with terms of reference which require it:

- to explore the opportunities, gaps and challenges in the UK telecommunications ecosystem, establishing where the UK can advance research, development and innovation (R&D&I) looking towards 2030 and beyond.
- to focus particularly on challenges and opportunities facing the telecoms supply chain and how to support and extend diversification activity in open networks.

2. The members of the EWG were selected to be representative of a wide cross section of the wireless networking ecosystem. Members contribute their time freely, and participate in an independent capacity, not on behalf of their organisations. Members are listed in Annex A.

3. The overall role of EWGs is to:

- Inform a better-shared understanding of key technical issues through knowledge sharing, leading to increased use of testbeds and other facilities across the ecosystem;
- Drive increased confidence in the security and resilience of the UK telecoms infrastructure and supply chain development by connecting with a broad supplier base, aiming to remove dependency on high-risk vendors;
- Consider measures that will accelerate the development and deployment of interoperable and open interface solutions, as well as catalysing the telecoms diversification strategy.

4. More specifically, our objective for 2023 was to deliver this report which identifies, within the scope of our wireless networking area:

- Areas of strength for the UK, providing opportunities to create strategic advantage (as highlighted by the Science and Technology Framework – which sets Future Telecoms of one of five strategic technologies).
- Gaps which need to be addressed and barriers to achieving advantage.

5. As well as inputs from the EWG members, our draft findings were presented in an open workshop to a wider set of experts, which led to refinement and extension of the recommendations.

6. It is expected that the work of the group will continue into 2024 in working jointly with other EWGs to build an overall roadmap (joint across the EWGs) to building UK capability to full strength.

7. The technical scope of the Wireless Networking EWG includes but is not limited to:

- Wireless access networks using both radio and optical media.
- Physical layer techniques
- Radio frequency engineering
- Signal processing
- Wireless network planning, optimisation and deployment
- Wireless network protocols and architectures
- Cellular, Wi-Fi, IoT and short-range communication systems including licensed and unlicensed systems for public and private applications.
- Non-communication applications of wireless technology such as sensing and broadcasting.

8. Within this technical scope, this white paper seeks to examine a wide range of ecosystem aspects which impinge on the opportunities to build strong UK capability in this sector.

9. The group has conducted a SWOT analysis of the UK capability in wireless networking, which led to the identification of the following key factors:

- Market Dynamics and Economics
- Research and innovation
- Standards and Intellectual property
- Policy and Regulation
- Infrastructure and facilities
- Skills
- Adoption and translation

10. While many of these are common factors for telecommunications beyond wireless, the group also identified the following technology areas as having special dynamics to consider for wireless networks:

- Semiconductor / baseband issues
- Radio frequency

11. Each of the above-mentioned areas is treated in a separate section which specifies:

- The current state of the art
- The current UK strengths
- UK gaps and barriers
- Recommendations for building UK capability

12. While the last 15 years have seen a relative weakening in UK activity in wireless networking, this comes against the context of world-leading achievements in the past and a strong retained early-stage research capability. We commence, therefore, with a reminder of some of the UK's past wireless achievements.

UK Wireless Networking Achievements

13. This white paper seeks to assess current wireless networking capability in the UK and opportunities to build it to full strength in the future. Amongst the assets which the UK has in this field is international recognition of a decisive role in wireless networking over its entire history.

14. Examples of significant UK wireless achievements with global impact include:

- 1831: Michael Faraday discovers electromagnetic induction.
- 1861/62: James Clerk Maxwell formulates his theory of electromagnetism, building on the work of Faraday (and others).
- 1896: Guglielmo Marconi files UK patent for a system of wireless telegraphy and demonstrates it in London, on Salisbury Plain and across the Bristol Channel, going on to demonstrate communication from England to France in 1899 and across the Atlantic from Cornwall to Newfoundland in 1901.
- 1897: The Marconi company is formed and goes on over a period of over a century to be responsible for key advances in radio including the diode vacuum tube, high frequency tuned broadcasting and short wave beam broadcasting.
- 1926: John Logie Baird demonstrates the world's first live working television system.
- 1935: Robert Watson Watt invents radar.
- 1964: Pye Telecom in Cambridge produces the world's first UHF handheld portable radio.
- 1981: Radio-paging code No. 1, usually known as POCSAG (1) published as an international standard for transmitting data to pagers, deployed in commercial devices internationally and still in use in some places today. The group was chaired by the UK and most of the early technical definition was done by UK engineers at Pye Telecom.
- 1982: Satellite dishes at BT's Adastral Park beam television signals for Europe's first satellite transmission service.
- 1983: The TACS (Total Access Communication System) first generation mobile cellular system is deployed in the UK's first two national mobile networks.
- 1980s: UK is a key contributor to the standards for security in the evolving GSM 2G mobile system. Notably Professor Michael Walker made major contributions to SIM-based security mechanisms, and went on to be Group Research and Development Director for the Vodafone Group. In 1985 Vodafone made the world's first GSM mobile call.

(1) Post Office Code Standardisation Advisory Group (POCSAG)

- 1985: After a group of researchers working at the University of Surrey in the late 70s (led by a young Martin Sweeting) decided to experiment by creating a satellite using commercial off-the-shelf (COTS) components, Surrey Satellite Technology Ltd was formed as a spin-out company to transfer the results of research into a commercial enterprise. The Company grew steadily and has worked with a wide range of international customers and partners, building and launching ~70 satellites for 22 countries over the following three decades.
- 1987: The UK is a co-signatory of the GSM MoU with European partners, enabling the deployment of pan-European and eventually global mobile digital (2G) telephony. The UK played a strong role in the development of the standard and associated technology, notably the introduction of the DCS 1800 (1800 MHz) variant, delivering spectrum capacity to allow competition between four UK operators.
- 1988: The UK created the MPT1327 standard for trunked radio communications, used very widely internationally for analogue private mobile radio systems for emergency services and commercial applications, with some systems still in use today.
- 1993: First Arm-based processor ships in a mobile handset. Today more than 99% of mobile smartphones and 65% of embedded IoT devices use Arm-based processors. These deliver very low power consumption, building on UK technology development going back to 1978 stimulated by a UK Government initiative aiming to put a computer into every UK classroom.
- 1998: Cambridge Silicon Radio founded as a fabless wireless semiconductor company and over the next ~15 years becomes a major multinational player, with particular successes in chips for Bluetooth and location (GPS/GNSS).
- 1999: The JOTS Forum (2) of UK mobile operators is formed to define technical specifications for shared and neutral host mobile coverage solutions, enabling cost effective deployment of in-building systems. These specifications evolve over the next 20+ years to encompass 2G, 3G, 4G and 5G, the latest small cell and Open RAN architectures and constitute a global first, transitioning from passive DAS sharing to active RAN sharing. An outdoor small cell extension is planned.
- 2005: Icera, a Bristol-based fabless semiconductor company launches the world's first single chip RF transceiver.
- 2005: UK wireless semiconductor company Picochip demonstrates femtocell concept at Mobile World Congress 2005 based on their baseband DSP devices, going on the produce world's first femtocell System-on-chip.

(2) Joint Operators Technical Specifications (JOTS)

SWOT Analysis

15. The results of a SWOT analysis conducted by the Wireless Networking EWG are shown below. These themes are examined in greater detail in the remainder of the document.

Strengths
- Academic research
- Legal, policy & regulatory environment
- Funding infrastructure
- Security landscape
- High-risk vendor mitigations
- Supplier diversity focus
- Government research funding
- Major vendor presence
- Focus on collaboration

Weaknesses
- Lack of scale
- Lack of supplier diversity
- Non-commercial mentality
- Aging workforce
- Regulatory burden
- Lack of coordination, commercialisation among academic centres of excellence
- Relatively poor access to funding

Opportunities
- Greater role for NTNs
- AI-driven cost & efficiency improvements
- New vendors add resilience
- Security expertise potential
- Academic excellence

Threats
- OpenRAN fails to improve diversity
- Supplier lack of accountability
- Over-reliance of US tech giants
- Lack of market size and scale
- Lack of 5G ROI
- Economic weakness
- Energy costs

Figure 1: SWOT analysis of UK wireless capability

Strengths

- Academic research: As noted by UK Research and Innovation (UKRI), a non-departmental public body sponsored by the Department for Science, Innovation and Technology (DSIT), the UK has an impressive track record when it comes to shaping the direction of telecommunications networks. (3) British universities, academics and industry have long been at the forefront of developing the technologies that help keep people connected, a trend that continues with UKTIN.
- Legal, policy & regulatory environment: The UK offers a robust and business-friendly environment to reliably expand, trade and invest, and the UK's language, legal system, funding environment, time zone and lack of red tape help make it one of the easiest markets to set-up, scale and grow a business. The wireless sector is no exception.
- Funding infrastructure for R&D & spin outs: There are several UK funding programmes for entrepreneurs designed to help businesses grow. (4) UKRI offers funding through Research Councils and Innovate UK, while Government-backed venture capital financing includes the Seed Enterprise Investment Scheme (SEIS) (5) and the Enterprise Investment Scheme (EIS). (6) Many tax reliefs for research and development (7) are also available including Patent Box, R&D Tax Relief and R&D Expenditure Credit.
- Security landscape: The UK wireless sector benefits from a strong focus on security. Most recently, the Telecommunications (Security) Act (TSA), (8) which came into force in October 2022, set out security standards designed to promote the resilience and integrity of core telecommunications networks in the UK. More broadly, the UK is considered to have world-class arrangements in place to mitigate national security risks to the telecoms sector.
- High-risk vendor mitigations: The UK took the lead in a European context when, following a ban on core network deployments, the decision was taken in July 2020 to halt the sale of new Huawei 5G equipment. In addition, all Huawei systems must be removed from 5G networks by the end of 2027. (9) The Government's decision was put on a legal footing in October 2022. (10)

(3) UK Research and Innovation, "Springboard for telecoms research and innovation" , ukri.org.uk, 4th October 2022, (accessed 2023-11-07)
(4) UK Government, Department for Business and Trade, "Access finance in the UK", great.gov.uk, 2023, (accessed 2023-11-07)
(5) HM Revenue & Customs, "Apply to use the Seed Enterprise Investment Scheme to raise money for your company" , www.gov.uk, 16th June 2017, (accessed 2023-11-07)
(6) HM Revenue and Customs, "Apply to use the Enterprise Investment Scheme to raise money for your company", www.gov.uk, 1st January 2016, (accessed 2023-11-07)
(7) HM Revenue & Customs, "Claiming Research and Development (R&D) tax reliefs", www.gov.uk, 21st July 2023, (accessed 2023-11-07)
(8) The National Archives, "Telecommunications (Security) Act 2021", legislation.gov.uk, 2021, (accessed 2023-11-07)
(9) UK Government Department for Digital, Culture, Media & Sport, National Cyber Security Centre, "Huawei to be removed from UK 5G networks by 2027", www.gov.uk, 14th July 2020, (accessed 2023-11-07)
(10) UK Government Department for Digital, Culture, Media & Sport,: "Huawei legal notices issued", www.gov.uk, 13th October 2022, (accessed 2023-11-07).

- Supplier diversity focus: Several initiatives have been put in place to promote supplier diversity in the UK telecoms market, with a focus on open disaggregation, standards-based compliance, demonstrated interoperability and implementation neutrality. November 2020's 5G Supply Chain Diversification Strategy, for example, set out the Government's plans to build an open, innovative and diverse 5G supply chain. (11)
- Government research funding: Government interventions are delivering investment across the sector designed to ensure that the UK remains at the forefront of wireless research. These include the Open Networks Ecosystem (ONE) competition, (12) which is part of the Government's £250 million 5G Telecoms Supply Chain Diversification Strategy, fostering telecoms R&D projects including Future RAN Competition (FRANC), Future Open Networks Research Challenge and entities like SmartRAN Open Network Interoperability Centre (SONIC Labs), UK Telecoms Innovation Network and UK Telecoms Lab. Other initiatives include the £28 million Innovate UK Small Business Research Initiative (SBRI) (13) and the £40 million Engineering and Physical Sciences Research Council (EPSRC) Future Telecommunications Systems Hubs funding. (14)
- Major vendor presence: While the Government is focussed on creating a more diverse and competitive supply base, the UK already benefits from the presence of many leading equipment vendors, which has led to investments in R&D as well as a degree of influence over product and standards development. In October 2022, for example, Samsung Electronics announced a new UK research group focussing on the development of technologies for 6G networks and devices. (15) In addition, in November 2022 Ericsson established a new research unit in the UK, with tens of millions of pounds allocated to 6G research and other breakthrough innovations. (16) Nokia, Parallel Wireless and Mavenir are amongst other vendors to also conduct R&D in the UK.
- Focus on collaboration: The UK has a strong heritage of infrastructure sharing, as exemplified by the Joint Operators Technical Specifications (JOTS) forum. (17) Although JOTS has a UK focus, it has managed to engage several global technology suppliers to collaboratively design and test common standard architectures for shared mobile networks. Most recently, the JOTS NHIB (Neutral Host In-Building) specification has led to an open 4G/5G small cell architecture for neutral host solutions.

(11) UK Government, Department for Science, Innovation and Technology and Department for Digital, Culture, Media & Sport, "5G Supply Chain Diversification Strategy" www.gov.uk, 7th December 2020, (accessed 2023-11-07).
(12) Open Networks Ecosystem Competition
(13) SBRI: Future Telecommunications Challenge
(14) Establish a future communications systems early-stage federated hub
(15) Samsung, "Samsung Electronics Announces a New 6G Research Group in the UK", 11 Oct 2022.
(16) Ericsson, "Ericsson in multi-million GBP 6G research program investment in the UK", ericsson.com, 22nd November 2022, (accessed 2023-11-07)
(17) Mobile UK, "Joint Operators Technical Specifications", Joint Operators Technical Forum, www.mobileuk.org, 2023, (accessed 2023-11-07)

Weaknesses

- Lack of scale: while the UK is highly innovative, pioneering a host of new telecoms systems and services over many decades, its relatively low population size means that there is insufficient scale for commercialisation based on the home market, since the UK accounts for only about 2% of suppliers' global mobile revenues11. Larger countries such as US can justify for example a new spectrum band in standards and phones based on their own needs alone. One example is Open RAN, and the fact that the UK's subscriber base appears unable to generate sufficient capital to fund new entrants' R&D costs. In addition, the link between UK operators and domestic suppliers has long been broken, resulting in a loss of capability in this area.
- Lack of supplier diversity: While, as previously noted, there have been several initiatives designed to improve supplier diversity, it is proving harder for new entrants to gain a meaningful foothold than many expected. As a result, UK mobile networks typically still comprise just two main vendors – Ericsson and Nokia – alongside pockets of others.
- Non-commercial mentality: Although the quality of innovation is high in the UK, the country often seems to lack both the necessary financial resources and drive to succeed, particularly when compared with markets like the US and China. The UK needs to regain its self-belief if it is to succeed and build on historic successes.
- Aging workforce: While in previous decades the UK wireless sector benefited from a highly skilled and regularly replenished workforce, the greater attractiveness of better funded sectors, such as Cloud and artificial intelligence (AI), has led to a loss of skills and aging staff for the wireless/wider telecoms sector. In particular, the middle-management tier has been depleted, with most workers now occupying either senior or junior roles.
- Regulatory burden: Mobile network Operators (MNOs) in the UK are experiencing declining margins and ongoing falls in ARPU (average revenue per user – around 60% lower than in 2007), (18) and some believe they are overburdened with regulation as well as often time- and cash-consuming licensing and legal requirements. Between the Huawei swap-out, Shared Rural Networks and the TSA, it is argued that there is often little scope for discretionary spend.

(18) Statista Monthly ARPU through post-paid mobile subscribers in the United Kingdom (UK) from 2007 to 2022

- Lack of coordination, commercialisation among academic centres of excellence: Several UK universities conduct world leading wireless research. Surrey University's 5G/6G Innovation Centre, for example, is one of the largest and most renowned academic research centres of its kind, and the University of Bristol has played a major role in the Government's 5G Testbeds and Trials programme. Other leading wireless centres include Sheffield, York, UCL, Southampton, Strathclyde, Belfast and Cambridge. However, they conduct only a limited amount of coordinated industry R&D and some lack the commercialisation specialists necessary to turn research into commercial reality, especially at a mid-Technology Readiness Level (TRL) stage. Meanwhile, policies regarding IP ownership, which often determine spin-outs' viability, vary widely; Cambridge owns none of its researchers' IP, while Oxford owns 100%.
- Relatively poor access to funding: Unlike the US, where private capital is readily available, funding routes for SMEs in the UK are more restricted, resulting in fewer large domestic players operating in the wireless sector. This has a knock-on impact on the salary levels UK companies can pay, and therefore the quality of graduates they are able to attract.

Opportunities

- Greater role for NTNs: The emergence of non-terrestrial networks (NTNs) and the growing role of hybrid terrestrial/satellite-based systems has the potential to make wireless networks considerably more resilient. NTNs could also lead to cost savings by providing coverage in remote areas that would be much more expensive to cater for using terrestrial networks.
- AI-driven cost and efficiency improvements: Assuming weaknesses such as a lack of training data can be overcome, MNOs' use of AI in areas like energy efficiency and network automation/optimisation has the potential to create much more efficient and cost-effective networks, with significantly reduced operating expenditure.
- New vendors add resilience: Notwithstanding ongoing concerns about their viability, the emergence of a host of new vendors has the potential to reinvigorate the UK market, while boosting resilience. In particular, a maturing of the OpenRAN market, which is likely in the next couple of years, could make wireless deployments both easier and cheaper.
- Security expertise potential: The UK's strong focus on security, including its ambitious Huawei removal programme and wider legislative focus, could see the country become a global leader in security, boosting the appeal of the UK as a wireless market.

- Academic excellence: There is scope for the UK to exploit its academic strengths and highly developed collaboration culture to create an effective university/industry bridging framework. This could be linked to R&D credits/incentives, pre-standards work and doctoral training, for example, to boost the sector as a whole. One area where UK innovation could be effectively applied is energy efficiency in the wireless sector.

Threats

- OpenRAN fails to improve diversity: OpenRAN may not, after all, lead to the hoped for increases in vendor diversity, resulting instead in a series of vendor alliances headed by a single dominant vendor. In this way, a small number of effective new incumbents could emerge, with no improvements in terms of diversity. Meanwhile, Samsung and NEC, which are being pitched as potential competitors to Nokia and Ericsson, could prove too small to present a meaningful challenge, especially if they are deployed only by single MNOs.
- Supplier lack of accountability: Greater supplier diversity has the potential to lead to conflict and a lack of accountability, blurring the current relatively straightforward lines of responsibility.
- Over-reliance on US tech giants: Following the decision to remove Huawei from wireless networks, the emphasis has been on improving vendor diversity to de-risk the supply chain and improve resilience. However, there is a risk that the UK wireless sector could develop an over-reliance on US tech giants instead, as hyperscalers Microsoft Azure, Amazon Web Services and Google Cloud tempt MNOs with cost-effective propositions which provide access to cutting-edge technology such as generative AI. A significant shift to eSIMs could also presage a loss of control for UK MNOs. (The Subscriber Identity Module, the SIM card, is being superseded by the embedded SIM (eSIM), a virtual digital equivalent that allows subscribers to switch more easily between phones and operators.)
- Lack of market size and scale: Given the relatively small size of the UK population and wireless subscriber base, there is a risk that international investors bypass the country and focus instead on markets with larger and faster growing populations, leading to stagnation.
- Lack of 5G RoI: Despite the high levels of capital expenditure (capex) allocated to 5G, it has so far failed to deliver increased revenue for MNOs, threatening their profitability and putting future investments at risk. Meanwhile, customer usage and demand are outstripping both MNO revenue and capex. These lessons are likely to be top of mind when the 6G cycle begins, potentially limiting investment.

- Economic weakness: Ongoing weak economic conditions and the impact of inflation on equipment costs are forcing MNOs to focus on reducing costs, at a time when wireless capex is already flat or down. This has the potential to impact future service provision and further damage revenue generation.
- Energy costs: High energy costs could make wireless services more expensive, with a knock-on impact on consumer uptake. These costs have an especially significant impact on wireless since most of the power consumption is in the radio.

Market Dynamics and Economics

State of the art

The UK public wireless market is highly competitive with challenging economics faced by providers of enhanced mobile broadband ('eMBB')

16. The UK market for consumer eMBB, which is the dominant revenue stream for the mobile sector with annual service revenue of c.£12 - 14bn, (19) is extremely competitive due to the presence of four independent mobile network operators ('MNOs'), a vibrant virtual operator ('MVNO') market and low consumer pricing.

17. Key points to note are:

- Average mobile broadband revenue per user ('ARPU') in the UK in 2022 was £14.86, (20) c.53% lower than the USA (c.£31.79) (21) and c.9% lower than the average of the EU-15 excluding the UK, and has declined by c.47% in real terms since 2010 through to 2022.
- Two of the four MNOs are currently not making a return of capital employed ('ROCE') that covers their group cost of capital (22)

18. To date low consumer pricing has been viewed as a successful outcome by Government and regulators, however these dynamics combined with changing macro-economics are now starting to impact investment capability at the point where UK ambition is to be a leader in 5G and beyond. Taking a wider view the inability of UK MNOs to invest may adversely impact the willingness of domestic and international companies to invest in and develop presence in the UK given lack of scale customer demand.

19. Outside of eMBB the market is more fragmented with a growing number of in IoT and fixed wireless access ('FWA') providing services to consumers alongside existing (e.g. eMBB) and new (e.g. cloud, mobile edge computing) services to enterprise clients; these organisations are likely to play an increasing role in the ecosystem and drive innovation and demand into the wider wireless telecoms supply chain.

(19) statista, " Telecommunications: Mobile retail revenue in the United Kingdom (UK) from 2007 to 2022", July 2023 (Accessed 2023-11-07).
(20) Statista, " Monthly ARPU through post-paid mobile subscribers in the United Kingdom (UK) from 2007 to 2022", statista.com, 2023, (accessed 18/11/2023).
(21) Statista, "Monthly ARPU from mobile wireless services in the United States from 1993 to 2021", statista.com, 2023, (accessed 18/11/23).
(22) UK Ofcom, "Ofcom's future approach to mobile markets", ofcom.org.uk, 9th February 2022, (accessed 2023-11-07)

What constitutes a Mobile Network Operator ('MNO') is changing rapidly

20. In the late 2000's the network run by a Mobile Network Operator ('MNO') was largely vertically integrated in terms of assets such as licenced spectrum, towers, radio access ('RAN') and core networks ('Core') and also supporting services such as estates management, field operations and network operations/control.

21. Accelerate forward twenty years to today and the norm is assets owned and operated by third parties. Towers have been commercialised e.g. Vodafone through Vantage Towers, transition to cloud core (e.g. 3UK's transition to a private cloud core) and outsourcing provision of RAN (e.g. CETIN and Cellnex Poland who provide wholesale active and passive services to operators). We are also seeing RAN equipment and the Core run on virtualised and increasingly shared platforms (e.g. Rakuten & Dish) and services such as field operations and network operation/control provided by outsourced providers.

22.The ultimate end point of this transition may challenge the inclusion of 'network' in the definition of MNO with differentiation increasingly achieved via service offering rather than unique infrastructure. This provides opportunity for the UK to develop expertise in areas such as software engineering and service design.

Private networks for enterprises are set to grow, a number of dedicated wide area networks have shifted onto public networks but some will endure and new ones will be required

23. The UK was relatively early globally to embrace the concept of spectrum sharing and trading, this was followed in 2019 by the release of 3.8 – 4.2 GHz into the shared access license framework ('SALF') which has catalysed the development of local (i.e. indoor, campus) enterprise private networks which have the potential to transform enterprise productivity across the UK.

24. Alongside these local private networks there are a number of dedicated wide area networks which remain critical to the UK economy, the most notable being broadcast television/radio and the Global System for Mobile Communications-Railway ('GSM-R') for the rail network. The trend over the last decade has been a shift of services such as private mobile radio for transport, public protection and disaster relief (i.e. ESN) and monitoring/control networks onto the public mobile networks.

25. However going forward there is a clear requirement for at least two new dedicated networks, namely the Future Railway Mobile Communication System to replace GSM-R ('FRMCS') and a critical control network(s) for the utilities sector. In the longer term there may also be demand for V2X networks for connected and autonomous vehicles and 'U-Space' connectivity for drone operations, however it is too early to confirm if these would leverage existing public networks or require dedicated networks.

UK satellite sector

26. Satellites and other non-terrestrial networks are important environments, both enabling and enabled by wireless communication technologies. We do not cover satellite in this section, instead we refer readers to the work of the UKTIN Non-Terrestrial Networking Expert Working Group.

KEY TAKEAWAY: FOR THE UK WIRELESS SECTOR TO CONTINUE TO SUCCEED IT REQUIRES ECONOMICALLY VIABLE PUBLIC NETWORKS ALONGSIDE DEPLOYMENT OF A NEW GENERATION OF PRIVATE NETWORKS AT A LOCAL AND NATIONAL LEVEL; IF ACHIEVED THIS WILL STIMULATE THE WIRELESS SUPPLY CHAIN BOTH DOMESTICALLY AND IN SOME CASES INTERNATIONALLY.

UK Strengths

The UK continues to pioneer network sharing and neutral hosting

27. Back in 2007 the agreement between T-Mobile and 3UK to share their 3G networks was ground breaking both in the UK and internationally. This triggered a wave of passive and active sharing across the mobile operators enabling new services to be deployed despite the challenging economics MNOs faced in the UK from 2010 onwards.

28. Fast forward to 2023 and the UK continues to see high levels of both passive (i.e. Vodafone and VMO2 via Cornerstone Agreement, BT/EE and Three UK via MBNL and third parties) and active sharing (i.e. Vodafone and VMO2 Beacon RAN sharing in non-urban areas. This has paid dividends for 5G where the UK has been significantly earlier to deploy than it was in 4G (i.e. within the first 20 countries to launch for the former vs. somewhere in the 50 -100 range for the latter).

(23) UK Ofcom, "Call for Input: Potential spectrum bands to support utilities sector transformation", ofcom.org.uk,7th September 2023,(accessed 2023-11-27)
(24) UKTIN, "UKTIN Non-Terrestrial Networking Expert Working Group", uktin.net, 2023, (accessed 2023-11-27)

29. This has resulted in a vibrant neutral host ecosystem, with companies such as Boldyn, Cellnex, Freshwave, Ontix and Wireless Infrastructure Group offering a range of neutral host solutions which provide significant economic and environmental benefit compared to single operator solutions.

Competitive intensity has driven cost effective and innovative service offerings for consumers

30. As described above the UK market is highly competitive which has driven significant innovation in the network infrastructure sector. Alongside this UK operators have pioneered innovative consumer concepts, notably ‘all you can eat’ approaches to voice and data services and more recently zero rated services for content such as social media and video. From a regulatory perspective, the UK has done well to balance the requirement for net neutrality with framework flexibility to let these services emerge.

31. The initial structure and evolution of the telecoms market in the UK led to limited fixed and mobile convergence, but the mergers between EE/BT and Virgin Media/O2 have started to change consumer offering, for example Virgin Media O2 utilising Volt benefits to double mobile data allowances and fixed broadband speeds. Seamless switching between fixed and wireless is crucial given that in excess of 70% (25) of mobile connections are via Wi-Fi. The more recent trend towards bundling either content or third party subscriptions (e.g. Netflix, Apple TV etc.) with fixed and mobile contracts further underlines the importance of seamless operation between fixed and wireless services.

The UK has shown some strong spectrum leadership, notably for private networks

32. From a position of challenge regarding launch of 4G the UK has achieved significant spectrum liberalisation, equalisation of holdings and release to support additional capacity and future technologies. The result of which has been the relatively early launch of 5G services in the UK by international comparison and ability to deliver significant capacity.

33. By making the 3.8 – 4.2 GHz available via a shared access license framework in 2019, to be followed by shared access to mmWave frequencies , the UK has enabled a range of new providers, such as neutral hosts and systems integrators, to successfully enter the market to provide next generation wireless services to enterprises. See Policy and Regulation section for more details.

(25) UK Ofcom, “Mobile Matters: Using crowdsourced data to assess people’s experience of using mobile networks” ofcom.org.uk, 9th September 2021, (accessed 2023-11-27).

34. Release of this harmonized spectrum in the UK ahead of a number of European countries has enabled UK organisations to develop expertise and know how which can be exported to other countries or across their international groups; demonstrating the value of timely spectrum release both to domestic networks and the wider wireless telecoms supply chain.

<u>The UK has made good progress in becoming a ‘pro deployment' environment for wireless services</u>

35. The update to the Electronic Communications Code in 2017 (26) and subsequent enhancement by the 2022 Product Security and Telecommunications Infrastructure Act (27) has significantly improved the deployment environment for both fixed and wireless networks. Crucially it has enshrined the criticality and ‘utility like nature’ of wireless connectivity to the UK and that the economic benefit to the majority (i.e. via network deployment) stands above land based interests.

36. This has been coupled with sustained activity regarding ‘barrier busting’, with the initial focus on fixed deployment expanding in recent years to include wireless services and associated infrastructure (e.g. access to public street assets). (28) Central Government and some local Governments have now started to take action to support their pro telecoms views, recognising the significant economic impact of network deployment and associated service take-up.

<u>The UK has provided strong support for early stage open network R&D via cross industry competitions</u>

37. Removal of high risk vendors in the UK led to the potential for a restricted vendor choice in the wireless hardware supply chain for public networks. Government was relatively quick to recognise this and put in place a strategy to (i) attract existing scale vendors (ii) support UK based R&D. Leading UK MNOs and parent companies like Vodafone, BT, Liberty Global and Telefonica support Open RAN associations like Telecoms Infra Project and O-RAN Alliance

(26) UK Public General Acts, “Digital Economy Act”, legislation.gov.uk, 2017, (accessed 2023-11-27)
(27) UK Public General Acts, “Product Security and Telecommunications Infrastructure Act 2022”, legislation.gov.uk, 2022, (accessed 2023-11-27)
(28) UK Government, “Digital Connectivity Infrastructure Accelerator (DCIA)”, 9 September 2021.

38. Government provided £250m of funding to date for vendor diversification which was largely distributed via the use of competitions focused on interoperability, use case development, university research and physical deployment; a proactive method which is relatively unique in a European context.

39. A significant benefit of this approach was consortium formation and associated interaction that might not have been done if left to the market. For example SMEs working with larger players and different parts of the value chain obtaining direct exposure to each other (e.g. passive infrastructure providers and system integrators).

KEY TAKEAWAY: THE STRUCTURE AND ECONOMICS OF THE UK MARKET HAS DRIVEN INNOVATION AND FOR IT TO BE A LEADER IN PASSIVE AND ACTIVE SHARING ALONGSIDE LEGISLATION AND SPECTRUM CONDITIONS WHICH HAS RESULTED IN HIGH LEVELS OF NETWORK COVERAGE.

UK gaps and barriers

Public wireless network depth and performance lags behind [many developed] nations

40. As noted above the UK has achieved high levels of base level outdoor mobile coverage, however network performance in terms of speed, latency and other performance criteria speeds lags behind other countries even within dense urban areas. Recent analysis indicated the UK is now 12th in Europe for performance. (29)

41. As a result, mobile network experience can be described as generally ‘thin’ by users and it does not enable reliable use of services such as video meetings and cloud based collaborative working.

42. Due to timing of additional spectrum release such as 3.6 GHz, new antenna technologies (e.g. M-MIMO) and aforementioned investment challenges the UK has not densified (e.g. via small cells, indoor solutions etc.) its public wireless networks to the same extent as others such as the United States and those in Asia. Indoor coverage remains a challenge and MNOs are typically not investing in this coverage with landlords/enterprise required to fund indoor systems.

(29) Ookla Insights Articles, Sylwia Kechiche, “5G in Europe: Reflecting on the Progress So Far and Mapping the Future”, ookla.com, 23rd February, 2022, (accessed 2023-11-27)

43. As a result the infrastructure platform (i.e. physical asset, transmission and power) is not available to enable rapid and seamless upgrade to a new technology (e.g. 5G); it is currently unclear what market event or industry will catalyse operators to undertake this densification.

44. In addition, limited scale and unfavourable economics in the UK can limit domestic operators' appetite to innovate with UK companies and enable them to scale, with greater innovation occurring at group company level.

<u>The business case for MNOs to invest in high quality wide area and indoor networks remains unclear</u>

45. MNOs are indicating that the investment case to deploy widespread high quality full feature networks (e.g. widespread population and geographic coverage of 5G SA) remain unclear. The resource and investment to develop wide area opportunities for non eMBB use cases is significant and would require MNOs to make significant changes to their go to market approach (i.e. shift from online and headcount light/SIM based sales into headcount heavy solution/consultative selling). There may be an opportunity to for mass market SIM products with particular latency and speed SLAs.

46. As a result the individual opportunity size for a non eMBB vertical use case may look attractive to non-MNO participants (i.e. £m of annual revenue) but when compared to £bn from eMBB and the aforementioned investment/transformation requirement may look unattractive to MNOs. This presents a risk to the UK that target 5G use cases with considerable economic benefit may not eventuate; for MNOs they look sub-scale/difficult to secure and for participants such as systems integrators it is impossible to deploy wide area networks economically without an eMBB anchor.

47. Noting for non-wide area requirement (e.g. indoor locations, campus environments) the developing private network ecosystem, comprised of MNO and non-MNO players, will likely provide a solution but cannot address economically wide area/nationwide requirements.

There is a risk that strong initial R&D investment in Open RAN does not convert into commercial opportunities for the UK

48. As noted earlier the UK has led well in funding initial trial and interoperability testing for open technologies such as Open RAN across a highly diverse set of projects and objectives. To date publicly funded projects have succeeded in achieving proof of concept status and in some cases a view of potential commercial exploitation of use cases. For them to make the leap to scale commercial opportunities they will require significant further support and funding from both the private and public sector and continued international engagement. Absent of this there is a risk they will continue to be interesting ideas which do not progress; noting this requirement for further support will require an evaluation of focus and impact.

There is a lack of scale UK vendors, impacting UK networks and export potential

49. At the start of public wireless telecoms deployment during the early 1990's the UK benefited from a diverse domestic and international hardware vendor ecosystem. Over time this has contracted to a point where remaining scale vendors are internationally based and low in number.

50. The UK Government and industry has recognised this sought to address via development of open technologies, which will bring with them disaggregation and virtualisation of key features and functions. This brings significant opportunity for the UK as the barriers to entry for creation of virtualised services (e.g. network operation, security) and software are considerably lower than hardware design and manufacturing. This is coupled with a potential shift by telecoms networks to use of commercial off the shelf IT hardware (e.g. standard servers) which retains a global and diverse ecosystem, and where it would be of questionable utility for the UK to seek to enter given huge market entry costs.

KEY TAKEAWAY: THE UK'S STRENGTH IN NETWORK COVERAGE IS NOT MATCHED BY NETWORK QUALITY WHERE THE UK LAGS BEHIND COMPARABLE COUNTRIES, THE BUSINESS CASE FOR NETWORK INVESTMENT REMAINS UNCLEAR AND IS CURRENTLY NOT SUPPORT BY A DOMESTIC VENDOR ECOSYSTEM.

Recommendations

51. Based upon our review of the UK wireless networks market we make four recommendations which seek to leverage current strengths and address gaps and barriers:

<u>Government, both national and local, needs to be the catalyst for high quality network deployment</u>

52. High quality wide area wireless networks are an imperative for both economic growth and societal development. The public sector is unique positioned to anchor deployment of additional mobile coverage, capacity and capability.

53. The three scale budgets at a national level are social protection, health and education and at local authority level they tend to be education, adult social care and police services and hence are likely to offer the best opportunity for digital transformation and associate anchor tenancies for advanced 5G services. In addition to this the Departments covering transport and energy, although smaller in size have compelling use cases for high quality network deployment.

54. By committing to digital transformation that leverages the mobile and nomadic (30) capability of public wireless networks the public sector should underwrite deployment and availability of network capability which the private sector can then leverage to deliver significant economic benefit. Project Gigabit has shown the scale of potential impact for the fixed networks, albeit in this case it was via direct subsidy. Procurement activity should of course remain a competitive process to drive value, but approaches such as shared risk/reward should be explored to help break the current impasse.

55. High quality networks which enable next generation use cases offer the potential to stimulate the wider supply chain to develop solutions, both physical and virtual, which have the potential for export.

<u>Continued action is required to improve the economics of the sector</u>

56. Absent of a dramatic shift in service revenue the economics of the UK mobile sector are likely to remain challenging. As a result ongoing regulatory and legislative focus is required to enable economic network deployment given the reduced capital available to UK operators.

(30) 'Nomadic' usage is static but in varying locations, as opposed to mobile which is 'on the move'

57. The UK Government should ensure completion of activity which has already commenced, notably the review of annual licence fees and swift and effective enablement of the PSTI legislation. Beyond this a further review of costs and externalities that wireless providers face should be commissioned with appropriate action taken regarding significant items.

58. At a local level continued action is required to ensure consistency of decision making that national and regional deployment requires across multiple local authorities; examples include access to public assets, planning, permitting. This should be combined with extensive education and support to enable local authorities to successfully pursue and support a pro-telecoms deployment agenda.

Open networks R&D needs to be focused on areas of likely significant commercial potential and/or UK market impact

59. Following the success of a diverse range of testing and trial activity there is now a need to focus future spend on fewer and more specific projects and areas which meet at least one of the following criteria.

60. The first should be where there is a viable route to scale domestic and international commercial potential (e.g. systems integration for Open RAN). The second should be where it is deemed critical for the UK to have its own domestic capability (e.g. cybersecurity for open networks). This review and selection process should be led via the UK Government but informed heavily via interaction with industry (including those adjacent to telecommunications), financial and research stakeholders. The UKTIN consultation structure of the Expert Working Groups and Strategic leadership forums are a good example, but consideration needs to be given to how this potential is maintained for the long term.

61. Once the focus areas are determined any subsequent public funding should prioritise progression into first commercial application and actions to scale, to ensure progression beyond the current pure R&D/ideas stage. In parallel there should be an attempt to align funding for university research to these priority areas and projects which have an end goal of commercialisation and to enhance diversity and resilience.

62. Achievement of this will result in:

- Increased R&D activity in the UK, for example from international equipment vendors
- Development of pioneering use cases that can drive benefits such as power saving, security, flexibility, coverage and gross value add in the UK
- Creating 'value-add' 5G capabilities that can be exported to other countries e.g. smart ports, smart manufacturing etc.
- Indirect benefit of increased competition in the vendor space with the aim to lower cost of network deployment for UK MNOs

<u>Economic support to enable start-ups to grow into scale players for domestic and export markets</u>

63. Across a number of sectors including Telecoms the UK has struggled to turn high class R&D into scale companies, with IPR often being acquired by much larger international companies at an early stage. Solving this problem is complex and will involve activity in a number of areas, hence Government should proactively support the development and scaling of companies development of scale companies as an overall objective for UK PLC, with a prioritisation of Telecoms given its status as both critical technology and critical national infrastructure.

64. One clear area of opportunity is university research and associated commercial spinouts. The UK should seek to emulate other countries, such as the United States, where there is much closer working between academia and venture capital.

KEY TAKEAWAY: FOR WIRELESS NETWORKS TO SUCCEED DOMESTICALLY THE ECONOMICS OF THE SECTOR MUST BE IMPROVED, BY THE PUBLIC SECTOR'S ANCHORING THE NEXT GENERATION OF SERVICES AND ACTIVITY TO EASE THE COST OF NETWORK DEPLOYMENT AND OPERATION. FOR THE UK TELECOMS SECTOR TO ACHIEVE SUCCESS IN INTERNATIONAL MARKETS THERE IS A NEED TO FOCUS R&D MORE ON ACTIVITY WITH COMMERCIAL POTENTIAL AND COMBINE THIS WITH AN IMPROVED EARLY STAGE INVESTMENT ENVIRONMENT.

Research and Innovation

State of the art

65. Research and innovation can be defined in terms of Technology Readiness Levels (TRLs), where the development of technologies at low TRLs (e.g. 1 to 4) can be considered to be research, while the elevation of this research to higher TRLs and its successful commercial exploitation can be considered to be innovation. The Business Enterprise Research and Development (BERD) statistics published by the Office of National Statistics estimate that UK research and development expenditure among companies working in information and communication systems totalled £12 Billion in 2021. The private R&D sector in the UK including companies such as Ericsson, Nokia, Samsung, Sony, Intel, InterDigital, Fujitsu, Toshiba, Qualcomm, etc. count for a few hundred UK-based researchers, which correspond to an annual R&D investment of tens of millions of pounds per year. As an example of this, Ericsson has announced a 10-year investment initiative which will provide tens of millions of pounds to employ 20 UK-based researchers and additional PhD students working on 6G technologies. Likewise, Vodafone is developing 5G innovation labs in Coventry and Manchester.

66. Private investment into UK research and innovation on wireless networking is supported by a rich public funding ecosystem, with diverse sources of funding available. Falling under the umbrella of the United Kingdom Research and Innovation (UKRI) organisation, the Engineering and Physical Sciences Research Council (EPSRC) provides funding for universities to conduct research and engage with businesses. In an August 2023 snapshot, the themes of “RF & Microwave devices” and “RF & Microwave Communications” comprised 101 grants, totalling £22.5M, which represented 0.8% of the EPSRC portfolio. Funding is offered for individual research projects, for programme grants (which typically comprise several universities and businesses) for CASE awards (which fund PhD students to work on industry-relevant projects) and for Centres for Doctoral Training (which typically fund dozens of PhD students), although there are open questions concerning the matching of these programmes with industry appetite.

67. Some of the most significant current EPSRC projects are focused on 6G topics including:

- three platforms have each received £2M of funding for around 25 universities to investigate topics in network of networks (TITAN), wireless and wired systems and spectrum (All-SPECTRUM), and cloud and distributed systems (CHEDDAR);
- three projects totalling £3.2M on Converged Optical and Wireless Access Networks, Next-generation Ultra-wideband Communication Networks and Deep Learning for the Physical Layer of Machine Type Communications, each awarded to University College London in collaboration with several UK and international universities and companies.

68. Likewise, Horizon Europe provides funding for UK universities and businesses to engage with partner organisations across Europe. Since Brexit in 2020, the UK engaged in a process to formalise its association with Horizon Europe, which only resolved in September 2023. However, in the meantime, UK participants were able to apply for Horizon Europe funding, with UKRI guaranteeing funding for successful UK applicants for Horizon Europe funding. Horizon Europe funding includes Research and Innovation Action (RIA) awards for research at low TRLs and Innovation Action (IA) awards for innovation at higher TRLs. Between February 2021 and April 2023, the UKRI guaranteed €1 Billion of Horizon Europe funding. The UK received €7.8 Billion of funding from the predecessor Horizon 2020 programme, between 2014 and 2020.

69. Some notable Horizon Europe frameworks include:

- CELTIC-NEXT is a €1.2B industry-driven initiative which has funded over 170 projects involving all the major ICT industry players and many UK SMEs, service providers, and research institutions;
- The European Smart Networks and Services Joint Undertaking (SNS JU) is a €250M programme, which is funding 35 projects, many of which include UK companies and universities, including BeGREEN, VERGE, Predict 6G, TERRAMETA, CENTRIC, 6G NTN, SUPERIOT, 6G-SHINE, 6G-SANDBOX, 6G-XR, TrialsNet and IMAGINE-B5G.

70. The Knowledge Transfer Network (KTN) awards Knowledge Transfer Partnership (KTP) funding for university researchers to work in UK businesses, in order to transfer research knowledge to the business and industry context to the university. In an August 2023 snapshot, there were two KTP placements within manufacturers of radio, television and communication equipment and apparatus, with a total grant value of £300k.

71. Research relevant to UK defence is funded by the Ministry of Defence (MoD), through the Defence and Security Accelerator (DASA). (31) Between April 2021 and March 2022, DASA ran a wireless communication networking and information theory challenge, which provided a total of £1.6M for 18 projects hosted at UK universities and businesses. Some projects focussed on antenna technologies, which were developed by University of Sheffield, University of Lancaster and Babcock Integrated Technology Limited. Meanwhile, other projects had a focus on networking protocols, which were developed by JET Engineering System Solutions, Etherstack Wireless Limited, London South Bank University and Rockwell Collins UK Limited.

72. Under the umbrella of UKRI, Innovate UK provides funding for UK businesses in the area of wireless networking. Notable examples of current Innovate UK projects include a £346k award to Ranplan Wireless Network Design Ltd and Queen Mary University of London on AI-powered Reconfigurable Intelligent Surfaces. Furthermore, Meshii Group Limited is the recipient of a £320k award, which is enabling them to develop innovative Wi-Fi network deployments for underserved populations.

73. The UK Government Department for Science, Innovation and Technology (DSIT) and formerly the Department for Digital, Culture, Media and Sport (DCMS) is leading on the UK Government's £250M 5G Telecoms Supply Chain Diversification strategy, which has comprised several funding programmes for UK wireless networking innovation. In 2017, the UK Government awarded £16M to the University of Surrey, the University of Bristol and King's College London, to collaborate on a 5GUK Test Network. This was followed by the 5G Testbeds and Trials programme, which provided a total of £30M for six use case trials of 5G deployments between 2018 and 2020. Further funding has also been provided for projects in urban connected communities, transport, industrial 5G, rural connected communities and security. The SmartRAN Open Network Interoperability Centre (SONIC) lab hosted by the Digital Catapult has hosted interoperability testing for O-RAN compliant basestation equipment from several manufactures. The Digital Connectivity Infrastructure Accelerator (DCIA) has provided £4M of funding to develop tools for managing wireless infrastructure deployment. Furthermore, the 5G Create programme has awarded £28M of funding to explore the use cases and applications of 5G. In 2022 and 2023, the Future RAN Competition (FRANC) provided a total of £36M for 15 consortia of UK universities and companies, to develop Radio Access Network (RAN) base-station equipment adopting the principles of Open RAN, in order to diversify the supply chain and address the UK critical infrastructure strategy.

(31) UK Government "Defence and Security Accelerator", gov.uk, November 2023, (accessed 2023-11-27)

Launched in 2023, the Future Open Networks Research Challenge is providing £29M of funding to enable UK universities to engage with large RAN vendors, in order to develop architectures to promote the interoperability of 5G equipment. Also launched in 2023, the UK Telecoms Lab hosted by NPL in Solihull has been funded by an £80M grant from DCMS to explore the security and resilience of 5G networks. DCMS are also leading international collaborations with the Republic of Korea and with India on wireless networking research and innovation. The Open Network Ecosystem (ONE) competition is providing £80M of funding for High Demand Density (HDD) use cases, RIC and other RAN software automation techniques, as well as processors, RF and other RAN hardware. Following the successful launch and completion of the above mentioned funding programmes, the UK Government has announced an investment of up to £100M to deliver its 6G strategy.

DEEP DIVE: DIGITAL CATAPULT

Digital Catapult has invested in Future Networks and telecommunications area since 2015, and it is now the largest focus area in Digital Catapult, with a well recognised position as a leading advanced telecommunications research and innovation organisation in the UK. Digital Catapult has built a unique capability in the telecommunications domain, bringing together a very strong technical team, together with telecommunication specialists in innovation and policy research. Digital Catapult has worked directly with 200 partners in 30 projects, has helped to introduce more than 650 digital companies into the world of advanced telecommunication systems/5G, and it has strong working partnerships with leading UK academic activities.

Digital Catapult is a founding (and lead) partner in UK Telecom Innovation Network, and also established in 2021, together with Ofcom, the SONIC Labs - for indoor and outdoor at-scale testing of open and disaggregated cellular systems, with funding by UK Government DSIT. SONIC Labs has worked with more than 20 vendors, and currently hosts about 59 OpenRAN products in its labs. Digital Catapult has built 14 5G testbeds across the UK, and currently operates 9 private 5G network testbeds from concert halls to Seagate factory and virtual production studios, with dedicated testbed and technology innovation acceleration programmes for UK SMEs.

74. There are several organisations and initiatives in the UK that can assist startups in the field of wireless networking. These organisations provide support, funding, mentoring, networking opportunities, and other resources to help startups grow and succeed. The SETsquared Partnership, Midlands Innovation and NxNW are startup accelerators that supports academics and high-tech startups across 22 universities, through the Innovation to Commercialisation of University Research (ICURe) programmes, which provide training, mentoring and funding to enable academics to explore the commercial market for their research. Entrepreneur First is an organisation that matchmakes co-founders from technical and business backgrounds. TechUK is an industry association that represents the technology sector in the UK. They offer various resources, events, and networking opportunities for startups working on wireless networking and related technologies. The Digital Catapult helps startups and scaleups develop and adopt advanced digital technologies, including wireless networking and 5G. They provide access to testbeds, expertise, and funding opportunities. Wayra UK is a startup accelerator backed by Telefónica, which focuses on startups developing disruptive technologies, including those in the wireless and telecommunications sectors. Cambridge Wireless is an industry community that supports innovation in wireless and mobile communication technologies. They offer events, networking opportunities, and industry insights for startups.

75. Some notable UK startups (at various stages of progression) in wireless networking include:

- Blu Wireless Technology, which develops mmWave modems and antennas;
- Zeetta Networks is a spin-out from the University of Bristol, which develops software-defined networking solutions that enable dynamic management of wireless and wired networks;
- Picocom develop Open RAN compliant baseband SoCs for the 5G physical layer;
- AccelerComm, which is a spin-out from the University of Southampton that develops IP to implement the signal processing of 5G;
- pureLiFi is a spin-out from the University of Edinburgh which has pioneered LiFi technology, which uses visible light communication to enable secure, high-bandwidth wireless networking;
- OpenSignal focuses on mobile network analytics, drawing upon crowd sourced data to provide insights into the performance of wireless networks globally;
- Ranplan Wireless offers solutions for wireless network planning, design, and optimization, catering to a wide range of wireless technologies and scenarios;

- Lime Microsystems offer a software defined radio chip and a range of boards, which can be used to implement various wireless networking standards;
- Filtronic is a designer and manufacturer of RF-to-mmWave components and sub-systems for mission-critical communication networks;
- Connectors Cables Specialists (CCS) are specialists in radio frequency coaxial connectors and cables;
- CableFree provides a range of 10+ gigabit wireless products including base stations, core infrastructure & consumer premises equipment;
- Quickline is a rural broadband provider.

UK Strengths

76. The UK has a world renowned reputation for producing high quality research and innovation. According to the 2023 QS World University Ranking, the UK is home to 9 out of the top 100 universities in the world for electrical and electronic engineering. This places the UK second, behind the USA with 24 of the top 100 and ahead of China with 8 of the top 100. Likewise, the ShanghaiRanking's 2022 Global Ranking of Universities reports that the UK is home to 11 out of the top 100 universities in the world for telecommunication engineering research. This places the UK third, behind China with 31 of the top 100 and USA with 23 of the top 100.

77. The topics listed in the state of the art discussion above demonstrate a strong alignment between UK research and global 6G wireless networking priorities. The IMT-2030 Framework identifies six usage scenarios that will define 6G, which are all strongly reflected in UK research:

- Immersive communication is reflected in the £2.4M of EPSRC funding for a 6G Sub-Terahertz Software Defined Radio Testbed hosted by the University of Sheffield, in collaboration with several UK and international companies;
- Massive communication is exemplified by the £530k Horizon Europe project on Secured and Intelligent Massive Machine-to-Machine Communication for 6G at the University of Essex;
- Ultra Reliable & Low Latency Communication (URLLC) is exemplified by a £412k Horizon Europe collaboration between the University of Sheffield and Ranplan Wireless Network Design Ltd on Service-centric Wireless Networks;
- Ubiquitous connectivity is reflected by the £1.8M EPSRC Cell-Free Massive MIMO for Future Wireless Networks collaboration between the University of Surrey 6G Innovation Centre, the University of York, Queens University Belfast and several UK and international universities and companies;

- AI and communication is reflected in the investment that UKRI has made in training 2000 PhD students between 2018 and 2032 at Centres for Doctoral Training distributed around UK universities;
- Integrated sensing and communication is exemplified by the £530k Horizon Europe project awarded to InterDigital and British Telecommunications Plc for research on joInt wireless commuNicaTion and sEnsinG by hologRaphic surfAce TranscEivers (INTEGRATE);

78. The UK has a significant strength in entrepreneurship, based on an ecosystem of solving complex problems. In terms of success in generating spin-outs, the 2022 Pitchbook University Rankings identified 8 UK universities among the top 100 worldwide. This places the UK second (albeit a distant second) to the USA, which is home to 58 of the top 100 universities. Meanwhile, dealroom.co reports that between 2020 and 2023, the UK ranked third in the world for VC investment into telecoms startups at $6.0 billion, behind the USA at $16.1 billion and India at $15.4 billion. Over the same period, dealroom.co reports that the UK also ranked third in the world for telecom startup exits at $9.9 billion, behind the USA at $52.1 billion and India at $19.5 billion.

79. In December 2021, the UK Spectrum Policy Forum 6G research initiative report identified 25 UK universities that are making significant contributions to 6G research. This may be considered to be a significant strength, granting opportunities for a wide pool of researchers to contribute. Indeed, the UK's reputation for high quality research and innovation, coupled with its native use of the English language (which is the world's most spoken second language), make it an attractive destination for researchers and innovators from around the world. Owing to this, the UK enjoys access to a large pool of talent drawn from around the world.

80. The UK has been a world leader in granting open access to research, mandating that all UKRI-funded research publications are made freely available to all, together will all underpinning research data. The UK collaborates internationally on open access to research, through several European research organisations, the international Organisation for Economic Co-operation and Development, as well as the international Research Data Alliance. This open research policy significantly reduces the barrier for international researchers to raise the profile of UK researchers through citation and collaboration.

81. As detailed in the state of the art discussion above, researchers and innovators in the UK have access to diverse sources of funding, which may be considered a significant strength. This ensures that not only does a diversity of different topics receive attention, but also a diversity of different funding models, which supports a wide variety of different types of collaboration and activities at different technology readiness levels. Indeed, the UK has a strong collaboration culture, which is made possible by the relatively tight geographical concentration of Great Britain and Northern Ireland, as well as by Government incentives. This is exemplified by collaboration between otherwise competing mobile network operators in areas of innovation, such as the Shared Rural Network.

UK Gaps and Barriers

82. While the UK enjoys high global rankings in terms of university research and spinout generation, this is achieved in spite of relatively low rankings for research and development expenditure. According to the OECD Gross Domestic Spending on R&D report, the UK ranks 6th in terms of gross spend and 12th in terms of percentage of GDP. While it could be considered that the UK has a strength in its efficiency in converting investment into outcomes, it can also be considered that more could be achieved with greater investment.

83. While the UK Spectrum Policy Forum recognised a significant strength in having 25 UK universities that make significant contributions to 6G research, they caveated this by identifying a lack of critical mass. This has resulted in much of the research being out of sight of the industry and policy maker stakeholders for 6G.

84. The UK faces challenges in recruiting individuals into research and innovation in wireless networking. While the high international standing of UK universities attracts talent from around the world into UK-based wireless network research and innovation, the pool from which this talent can be drawn is limited by several factors. These include the high cost of visas and tuition fees for international PhD students studying in the UK, particularly compared with e.g. Germany where no tuition fees are charged for any PhD students. Furthermore, Brexit and the only-recently-resolved UK status in Horizon Europe has hampered recruitment from Europe, while the Academic Technology Approval Scheme (ATAS) has hampered recruitment from China, for example. Similarly, the well-known STEM shortage in the UK limits the pool of home-grown talent into wireless network research and innovation. Likewise, PhD stipends do not compare with graduate salaries, particularly in high-paying areas adjacent to wireless networking such as AI and software engineering, which limits recruitment into wireless networking research and innovation.

85. There is a well-recognised challenge of translating research into innovation in the UK. Universities typically lack a critical mass of the diverse commercial and technical skills that are required to raise the technology readiness level of research to the level where is can be adopted by industry. Incentives for researchers to engage in enterprise and entrepreneurship can vary between universities and so many academics may instead prioritise research and education. The pathway from research to product-market fit is long and maintaining funding throughout that journey can be challenging. Furthermore, while several funding routes exist for projects in which industry 'pulls' research from universities, there are fewer funding routes for projects in which university 'pushes' research into industry. More specifically, it is typical for industry partners to lead projects that provide public funding for industry and universities to collaborate. Examples of this include Knowledge Transfer Partnerships, Innovate UK projects and DSIT-funded projects. While it is typical for university-led EPSRC projects to include industry partners, these partners typically provide funding to the project, rather than receive it.

86. More broadly, there is a lack of incentivisation for operators and large international companies to engage with and adopt research and innovation from UK universities and SMEs. This creates a significant barrier to entry, which makes it difficult for UK universities and SMEs to access market insights, use cases and data. In order to overcome the barrier to entry, UK startups and university spin-outs are often required to raise substantial private investment in order to build teams having diverse commercial and technical skills, to raise the technology readiness level of their innovation, to reach international markets and to fund trails with operators and large international companies.

87. While dealroom.co reports that between 2020 and 2023, the UK ranked third in the world for both VC investment into telecom startups and for their exits, the ratio of these amounts suggests a return on investments of only 1.65x, which is half the 3.23x achieved by the USA. Furthermore, of the $9.9 billion raised during exits of UK telecoms startups, only 16% of these funds originated from the UK. By contrast, 75% of the funds raised for exits of USA telecom startups originated from the USA. These results suggest that the UK struggles to grow telecoms startups, which instead tend to get sold overseas before they have opportunity to generate maximum value. This suggests that investors do not recognise UK telecoms as the best place to invest and highlights a difference in mentality between the UK and the USA.

Recommendations

88. In December 2021, the UK Spectrum Policy Forum identified several areas as priority opportunities for the UK Government to incentivise for 6G research and innovation, as listed below. Two years later, these areas remain relevant, owing to their alignment to the six usage scenarios identified in the IMT-2030 Framework as defining 6G:

- Widespread coverage to prevent the manifestation of a "digital divide" and to contribute to improved health and social care outcomes and future transport ambitions, in alignment with the IMT-2030 connecting the unconnected overarching aspect.
- Innovation in spectrum management (e.g. through the use of automation and AI), to improve spectrum efficiency and densify spectrum sharing, particularly in the low frequency, mid and mid high frequency bands suitable for mobile connectivity, aligning with the IMT-2030 AI and communication priority, as well as the ubiquitous intelligence overarching aspect.
- Economic viability of roll-out of next generation mobile infrastructure (through enabling new service possibilities or significant cost savings), in alignment with the IMT-2030 priority of extending 5G enhanced mobile broadband (eMBB) into 6G immersive communication.
- Alignment with the Government's net zero targets, which aligns with the sustainability overarching aspect of IMT-2030.
- Seamless connectivity – a "network of networks" (for example the integration of terrestrial and non-terrestrial networks) with high security and resilience, which aligns with the IMT-2030 ubiquitous connectivity priority and the security/resilience overarching aspect.

In order to further develop the alignment with the IMT-2030 Framework, it is recommended to add the following priorities to the list above:

- Massive communication, as an extension of the massive machine type communication (mMTC) focus of 5G, to consider topics including non-orthogonal multiple access;
- Hyper reliable low latency communication (HRLLC), as an extension of the ultra reliable low latency communication (URLLC) focus of 5G;
- Integrated sensing and communication, to consider topics such as positioning.

89. The UK Spectrum Policy Forum also recommended that participation in an approved "collaborationo model" should be a condition of 6G research funding provided to universities. This would enable Government, regulators, mobile network operators and relevant industries both in the UK and in partnering countries to systematically engage with the 6G research community. This would also increase the incentives for academics to engage with enterprise and entrepreneurship. As an example, EPSRC-funded PhD students could be required to submit a stake-holder engagement report for assessment as part of their regular progression reviews. It may be expected that stake-holder engagement would ensure that PhD research is conducted with consideration of real problems faced by real applications of the research. Furthermore, it may be expected that stake-holder engagement would create new opportunities for collaboration, funding, employment, licensing, investment, etc, which would result in greater and more effective transfer of research into innovation.

90. The DCMS-led international collaborations with the Republic of Korea, India, and Germany on wireless networking research and innovation are recognised as being valuable for promoting international collaboration. It is recommended that a systematic approach to the creation of more international collaborations like these should be adopted and should target key partners, such as the USA and Europe. In particular, collaboration with international commercial organisations such as Qualcomm, Apple, Ericsson and Nokia should be developed.

91. Furthermore, the UK Spectrum Policy Forum also recommended that the Government should be organising a managed and coordinated national approach to efficiently and effectively take the results of relevant UK 6G research projects into global standards bodies, giving Universities, the research community, and UK SME's more impact acting collectively and taking due account of their needs. This could be achieved by creating a virtual centre of excellence to bring together the pockets of excellence spread across the UK and build critical mass. This could support the adoption of UK patents into international standards and their licensing to companies around the world. It can also support the development and transfer of skills for individuals working in the UK.

92. The support provided for the generation and development of startups and SMEs in wireless networking by TechUK, Digital Catapult, Wayra UK and Cambridge Wireless is well recognised. Furthermore, ICURe and Entrepreneur First are renowned for startup incubation across a wide variety of sectors. However, given the strategic importance of wireless networking to the UK, it is recommended DSIT should partner with relevant and proactive innovation organisations on an occasional basis to create some cohorts targeted specifically at wireless networking. This could provide a platform to introduce support from UK operators and international vendors, similar to the approach adopted by the 5G Open Innovation Lab in the USA. By exploiting the value chain in this way, this approach can be expected to create critical mass, which can reduce the barrier to entry.

INTERNATIONAL EXAMPLE: 5G OPEN INNOVATION LAB

The 5G Open Innovation Lab is a US-based startup accelerator, open to innovators and entrepreneurs from around the world, who are developing new 5G technology solutions and use cases. Founded by leading global technology companies, including Intel, T-Mobile, and Microsoft, this support is leveraged to provide startups access to mentorship, funding, technical support, and access to cutting-edge 5G infrastructure. Through a structured cohort-based program, participants embark together on a 12-week journey to refine their ideas, test their innovations, and gain insights to scale their solutions in the emerging 5G ecosystem. The 5G Open Innovation Lab has supported over 100 startups, which have gone on to raise investments summing over $600M.

93. The UK's approach to open research and open data is widely recognised as being world leading. An opportunity to build further on this foundation is presented by incentivising UK operators to make data on network deployments, network traffic, channel conditions, etc available to researchers. Here, it is recognised that there are legal and commercial challenges associated with sharing sensitive data and so an appropriate legal framework would be required to support this.

Existing examples of frameworks for sharing network data include the Colosseum ColO-RAN Dataset and the RF Data Factory datasets. Making datasets such as these available could be expected to significantly boost advances in AI and would provide market intelligence that would be invaluable for steering UK startups and SMEs. Concerns about the commercial sensitivity of this data can be addressed through obfuscation or by using the data to train generative AI models, which can generate representative data for use in research purposes. More broadly, it is recommended that funding routes be created that UK universities, startups and SMEs can use to push their research and innovations into large international organisations and operators. Here, funding should be provided to the industry partners, in order to incentivise their participation.

94. Furthermore, universities should be encouraged to develop a multi-disciplinary approach to innovation in wireless networking, which includes software engineering, chip design, AI, business and commercialisation, for example. This would have the benefit of exposing wireless networking to more researchers and innovators, as well as enabling the technology readiness level of innovations to be raised at an accelerated pace.

Radio Frequency Aspects

State of the art

95. RF and microwave technologies including component and system level hardware are the fundamentals in the operation of modern communication systems, enabling wireless connectivity, high-speed data transmission, long-distance communication, and a wide range of applications in telecommunications, healthcare, defence, and scientific research. Their importance will only continue to grow as technology advances. Given the recent supply chain crisis and current geological landscape, sovereign supply chain and/or collaboration with friendly actors has become a critical element in future road mapping activities.

96. The exclusion of some vendors from the market, while clearly a risk to critical infrastructure, is also an opportunity for the UK, which has a solid base on which to build, with a rich history of innovation in RF and wireless technologies. This must however be tempered by two key dynamics, one is the ageing profile of RF/Microwave experts with many within 5-10 years of retirement, which means to exploit this talent we need to take the opportunity to train new young engineers and the second being UK business cost structure, which, particularly in telecoms (a strongly margin driven market), leads to the need to operate in more niche, low to mid volume applications, this could however, if fully exploited give the UK a leading position in key critical technologies along with the ability to trade such capabilities with other friendly actors.

Future Direction:

97. The future direction of travel for RF and microwave technologies for telecommunications applications is reasonably well understood and is typically incremental as we move from generation to generation of wireless networking, with ever increasing data demand and numbers of subscribers leading to a requirement for higher and higher bandwidth network implantations. This leads to a coupled requirement to move to higher frequencies where larger chunks of spectrum are available to allow for wider channel bandwidth, the same is true for the user side (typically sub 6GHz with up to 100MHz channels) and for wireless backhaul albeit as the data requirements of backhaul are much greater, the frequencies used are also much higher with state of the art system operating as high as E-band (71-86GHz, employing UK hardware from Filtronic) with roadmaps to D-band (up to 175 GHz)

98. Key trends include:
- Higher frequencies
- Deployment of compound semiconductors
- Higher levels of integration
- Advanced packaging
- Thermal management
- Cost reduction

UK Strengths

99. The UK has a rich history in RF and Microwave with notable claims to fame including the invention of radar and the world's first GaAs MMIC devices conceived at Caswell. Indeed, for many years the UK was a significant global force with large vertically integrated companies employing thousands of engineers, perhaps the most notable being GEC-Marconi. After the telecoms boom and bust the landscape has changed significantly and the UK RF and microwave community is no longer shaped by large defence and telecoms contractors. The legacy however are several clusters throughout the UK with a vibrant ecosystem of small to medium size enterprises supplying the telecommunication, space and defence markets. In terms of academic prowess, the UK continues to hold high regard in RF and microwave engineering and has a number of active, world leading research groups.

Notable Industrial Clusters and players

100. As noted, the UK has a vibrant ecosystem of small to medium size businesses in the UK including fabless design, filter design, RF module and sub-system design and manufacture, antenna and active antenna design, specialist consultancy services, packaging, integration and test & measurement. Outlined below are some of the notable industrial players grouped geographically.

101. East Midlands Stemming from the original Plessey research centre Caswell (noted above as the birthplace of the GaAs MMIC) there is a cluster of companies including Microwave Technology, a manufacturer of GaN Power Amplifiers, Enterprise control Systems, and countermeasures. SJ Technologies, who design a range of passive RF and Microwave components. Intelliconnect, who have a manufacturing facility producing connectors, cables and adaptors. Amphenol who have a facility for the manufacture of base station and small cell Antennas.

102. Lincolnshire: There is a similar pocket of microwave businesses in and around Licon, resulting from the various GEC-Marconi sites originally in the area. These include Linewave, who design and manufacture mmWave subsystems for satellite communication and defence. Teledyne e2V, who have facilities in Lincon and Chelmsford manufacturing high power RF systems from magnetrons to semiconductor devices and subsystems along with underlying core technology around ADCs and DACs.

103. London and surrounding counties Companies include TMD Technologies (recently acquired by CPI) who design and manufacture microwave power modules and travelling wave tubes. Chelton (formally Cobham) who manufacture a range of antennas and RF components such as diplexers, splitters and couplers. Lime Microsystems are based in Guildford and specialise in RF transceivers and SDRs. Surrey Satellite (now a subsidiary of Airbus) design and build small satellites and payloads. API Tech (formally Cobham) who have a UK site in Milton Keynes, where they design and manufacture Radar systems and modules and components for defence and space. Ensilica based in Oxford a fabless design house specialising in wireless IP for telecommunications and space All.Space based in Reading is a specialist in phased array antennas mainly for satcom applications. LA Techniques a specialist in test and measurement equipment. The wireless unit of Viavi solutions manufacture test and measurement equipment aimed at the base-station market. Also in the area is the UK site of Anristu and Rhode and Scwartz with both major players in the test and measurement with R&D including software and application specialists.

104. Cambridge There is a further cluster in and around Cambridge with significant global players including ARM and Qualcomm (who acquired Cambridge Silicon Radio in 2015) and also includes the UK headquarters of Huawei Technologies R&D. Other notable wireless companies include PRFI, a fabless MMIC design house. Hanwar Phasor, a company specialising in phased array antennas including fabless design. Pico Technology a leading developer of test and measurement equipment. VIAVI Solutions (previously Cobham/Aeroflex/Marconi), a leader in wireless test and measurement with UK-based 6G R&D. Cambridge is also home to some leading design consultancies covering a range of markets including telecoms, space and defence including Plextek, Cambridge consultants, PA consultants and the Telcom Technology Partnership (TTP).

105. North of England There is another significant cluster in the North of England stemming from the research prowess of Leeds University, including a significant spin-off Filtronic which went on to be one of the most successful UK spin-off companies reaching £1 Billion market capitalisation in 2000, after the telecoms crash a number of business units were sold, Filtronic now has 120 employees based across 3 sites specialising in mmWave wireless backhaul, RF subsystems and filters for space and defence along with an advanced device packaging and assembly capability, they have also seeded a cluster of other companies in the area including Slipstream Design a design company specialising in RF, microwave and digital subsystems. Teledyne defence and Space (formally Filtronic defence). Radio Design an RF and microwave filter design specialist. Saras Microwave specialising in power amplifiers and filters. Diamond Microwave a GaN power amplifier specialist. Viper RF a fabless MMIC design house focused on telecommunications and space. Inex is a semiconductor foundry with a focus on GaN RF devices for telecoms and defence. Global Invacom (Skyware) are a specialist VSAT designer and manufacturer. BSC Filters, based in York is a specialist in RF and microwave filter assemblies for defence and space.

106. South-West and Wales South Wales has formed a cluster around compound semiconductors, a fundamental technology building block for future wireless systems, in terms of RF/Microwave companies there is Focus Microwaves a test and measurement company, near by in Bristol there is Blu Wireless a mmWave private network specialist and Microwave Amps Ltd a specialist in GaN power amplifiers. ETL are based in Herefordshire and manufacture RF distribution systems and satcom equipment. Also based in Herefordshire are Teledyne Labtech a specialist in RF and microwave PCBs.

107. South of England/Isle of Wight Two more notable smaller clusters can be found in Devon/Cornwall and on the Isle of Weight. In Devon there is Quasar Microwave Technology who are waveguide specialist. In Cornwall there is Flan Microwave, another Waveguide specialist. On the Isle of Wight there is Milmega who specialise in high power amplifiers and sub-systems and Vectrawave which develops MMICs and multichip modules for comms, defence and space.

108. Alongside the SMEs noted in this section there are also significant defence players with strong RF and microwave teams including Leonardo, Airbus defence and space, BAE systems and MBDA, all use a mix of internal resource and leverage the UK supply chain.

Academia and RTOs

109. The UK has established world leading research groups centred around wireless and telecommunications covering everything from semiconductor device to system level research. This is supplemented by research organisations aimed at linking academia to industry notable examples are highlighted below –

- Bristol University - The academic research in wireless telecommunication from the University of Bristol spans from low TRLs to higher TRL supported by a testbed providing system level research with an end-to-end data service delivery in an outdoor urban (around Bristol harbour) and indoor campus (at MVB & BDFI sites). The system level research aims to evaluate telecommunication use cases as well as the science of the network elements driving the telecommunication solution & capabilities. Hosts a testbed with an end-to-end standalone 5G/B5G service delivery capability, based on O-RAN, multi access technologies like WiFi-7 & LiFi, along with 5G air interface, and the multi access technology RIC research capability. Research focus on networks of networks, including wireless, optical, satellite, and quantum technologies.
- Cardiff University - Semiconductor research, device characterisation and modelling, power amplifier design and optimisation
- Sheffield University - Semiconductor research, mmWave/THz characterisation, and power amplifier design
- Birmingham University -Novel Antenna design and additive manufacturing
- Glasgow University -Semiconductor device technology), University of Surrey (/6G Centre including system level design and advanced antennas
- Surrey University – System level research at their 5/6G centre
- Queen Mary University – Specialists in advanced antenna design and power amplifier design
- Southampton University – Novel materials and techniques and microwave photonics
- Cambridge University – Semiconductor research
- Cranfield University – Wireless communication and radar for defence
- Lancaster University – Research in high power travelling wave tube amplifiers up to D-band.
- Durham University – Radio propagation, radar imaging, channel measurements and characterisation
- UCL – Wireless communications, MMICs and distributed mmWave amplifiers
- Herriot Watt – Novel microwave filters

- NPL – Advanced characterisation and metrology
- Satellite Applications Catapult – Support for industry including testing high frequency faculties and antenna test.
- Compound Semiconductor Applications Catapult – Support for industry including advanced RF and microwave laboratory.
- IMEC – Interuniversity Microelectronics centre, headquartered in Belgium with a footprint in the UK. One of the world's largest research houses for semiconductor technology including packaging and integration.

UK gaps and barriers

110. Skills – Recruitment in the RF and Microwave industry has been challenging for at least the last two decades, with a continued reluctance from young engineers to move into what is perceived as a highly technical and mathematical subject area. This has led to an aging expert base with a significant proportion of experts now within 5-10 years of retirement, this is critical as action is needed urgently to ensure the skill base is not lost entirely.

111. International competition - Due to business cost in the UK companies are often priced out of markets as products become commoditised, this means that to be successful UK businesses must operate in more niche areas and/or stay at the cutting edge of technology to maintain a competitive advantage.

112. Cost of Entry – Can be significant. any product development requiring custom semiconductor development leads to high cost of initial development, but the use of COTs parts is difficult in telecommunications due to the slim margins on sales. manufacture for RF and Microwave, particularly at higher mmWave frequencies requires specialist manufacturing and Test and measurement equipment which is costly and time consuming to commission and optimise.

113. Brexit – Has limited free movement of staff within Europe, even with efforts to reduce the burden on visas some have already relocated back to mainland Europe over future security concerns. Anecdotal evidence from universities that it is affecting intake particularly for PhD and postdoc programs.

114. Lack of a system integrator - The lack of a UK based system integrator limits the supply opportunities for the UK supply chain as there less opportunities in foreign markets.

Recommendations

115. International collaboration - While UK companies may thrive in niche, high value elements of the supply chain, collaboration will be key to maximise the market opportunity and to embed UK content in future wireless systems.

116. Low-cost access to test facilities – As mentioned, access to test facilities can be a significant barrier to new entrants to the market, although there are centres with relevant equipment these are often cost prohibitive to access. The best model seems to be to embed equipment within an industry setting with a core partner so the equipment is regularly used but remains open for access to others.

117. Government procurement initiatives although not the largest buyer of telecoms infrastructure the UK still has significant spending power, could this be used to convince suppliers to include the UK supply chain? If successful could lead to design into a product that would then be sold in other territories.

118. UK Strategy to cover multiple markets For wireless technology and related semiconductors there is significant crossover from telecommunications requirements with those of defence and space, investments should be pooled and the roadmap developed so the UK has its sovereign needs met while maximising the commercial opportunities for the supply chain.

119. Focussed UK roadmap leveraging UK academic base Linked to above ensure the academic base buys into the same roadmap with a future looking perspective.

120. Commercialising academic research – Once we have alignment between the academic and UK strategic roadmap the next issue to solve is the commercialisation of academic research, all too often the only option is a spin-out company which either fails due to lack of money or commercial acumen or quickly get bought by large international companies. Could the Government invest to protect valuable IP then partner with the supply chain to take it to market. One model would be to recover the investment by licencing the IP.

121. Coherent drive on Skills - Here something needs to change as skills have been an issue for decades. Some combination of education and selling the industry combined with incentives (e.g. bursaries for students to study) may be a good combination.

Baseband Semiconductor issues

State of the art

122. The focus of this section (32) is on the implementation of baseband processing for wireless products, both network and client devices. Here we define baseband processing as the physical layer (L1) and those parts of L2 of the protocol stack that are tightly coupled with L1 and together create and decode the "over-the-air" signals. These processing blocks comprise of a combination of digital signal processing, resource scheduling, control and management functionality and are almost invariably performed on digital processing devices fabricated from silicon.

123. This area is highly technical and specialised in terms of the required algorithmic content and sophistication of the implementation technology and the UK has significant historical strengths in both (see table in 'UK Strengths'). The silicon content (and any software running on it) of most equipment embodies the commercial and technical value of that equipment and baseband processing together with the RF elements (see the following section) embody the actual "wirelessness" in a wireless network.

124. Here we should consider the "what" and the "how" of the state of the art of baseband processing. Starting with the "what" - most wireless systems are designed, built and tested to a national or international standard specification. The types of wireless applications requiring the sort of baseband processing considered here are (by standards body):

(table included on next page)

(32) Note that a separate Expert Working Group deals more generally with semiconductors and materials. This section is on the wireless-specific elements.

Body	Application	State of the art standard
3GPP	Mobile Cellular Systems	5G NR Release 18 (33) (5G Advanced) -> 6G
IEEE	Wireless Connectivity Systems	Wi-Fi 7 (IEEE 802.11be) (34)
Bluetooth SIG	Wireless Connectivity Systems	Bluetooth 5.4 (35)
Connectivity Standards Alliance (CSA)	IoT connectivity	Zigbee PRO 2023 (36)

Table 1: Latest standards-based wireless technologies (non-exhaustive list)

125. In mobile cellular systems, infrastructure products need to consider the capability limitations of legacy handsets and thus, in many networks, must provide support for previous generations of a standard so knowledge, skills and IP for older generations such as 4G and prior remain important for new product development regardless of what the most recently published version of the specification. This constraint or similar exists in handsets (due to the diversity of generations used within an operator's network and between operators' networks). It also exists in other wireless standards above.

126. Moving to the "how", the devices that can be used to implement baseband processing vary in nature primarily due to their computation architecture and chosen optimizations between various trade-offs of key metrics e.g., flexibility, performance, cost and power consumption. The following is a brief, high-level overview of the principal types of silicon devices used in baseband processing to further characterise opportunities in baseband semiconductors:

- Field Programmable Gate Arrays (FPGAs): These are reprogrammable logic devices typically used for the higher speed processing required nearer the input/output to antennas. This performance and flexibility is traded off against high power consumption and cost relative to some other types of device.

(33) 'Release 18', 3GPP. Accessed: Nov. 27, 2023. [Online]. Available: https://www.3gpp.org/specifications-technologies/releases/release-18
(34) C. Deng et al., 'IEEE 802.11be Wi-Fi 7: New Challenges and Opportunities', IEEE Communications Surveys & Tutorials, vol. 22, no. 4, pp. 2136–2166, 2020, doi: 10.1109/COMST.2020.3012715.
(35) 'What's new in Bluetooth v5.4: An overview', Bluetooth® Technology Website. Accessed: Nov. 27, 2023. [Online]. Available: https://www.bluetooth.com/bluetooth-resources/whats-new-in-bluetooth-v5-4-an-overview/
(36) 'Zigbee | Complete IOT Solution', CSA-IOT. Accessed: Nov. 27, 2023. [Online]. Available: https://csa-iot.org/all-solutions/zigbee/

- Digital Signal Processors (DSPs): These are specialized microprocessors, programmed in software, with architectures and instruction sets (and integrated accelerators) optimized to perform digital signal processing algorithms efficiently.
- System-on-Chip devices (SoCs): SoCs are composed of an integration of a range of building blocks into a single silicon die (chip) e.g. hardware implementations of demanding digital signal processing blocks such as channel decoders, DSP processor cores programmed by software and host general purpose processor(s) for protocol stack, control and management functions. SoCs are carefully crafted to get the most appropriate balance of functionality, flexibility, cost and power consumption for the application.
- General Purpose Processors (GPPs or aka CPUs): These are the descendants of the original microprocessors of the 1970s and are typically the device of choice for laptop and desktop personal computers and data centre servers. They come in a wide range of levels of performance and some types of GPP are now being used to perform some of the baseband processing of Open RAN implementations. (37)
- Graphics Processing Units (GPUs): Originally architected and produced for high-performance graphics processing in personal computers, GPUs have grown significantly in compute power and are now used extensively in AI. It has been proposed that they may implement baseband processing (at least the physical layer portion) in wireless infrastructure (as a conventional "DSP"). (38)

127. Baseband processing in wireless network infrastructure could be built out of any or a combination of any of the above but typically the power consumption, cost and size requirements of a client device such as a mobile phone are such that only a SoC will do and often may integrate other functionality required into the same device. In the 'UK strengths' section below, we will highlight that the predominant relevant silicon development activity in UK over the years has been in DSP/SoC-style devices, with FPGA, GPU and GPP devices invariably coming from large established incumbents.

128. Silicon IP (Intellectual Property): The list above encompasses physical devices but there is a segment of the industry which focuses on designing subcomponents as IP cores for the SoC devices that others are producing e.g. ARM for GPP cores, (39) CEVA for DSP processor cores. (40) There are Silicon IP producers, including in the UK, which produce functional blocks for wireless baseband processing. (41)

(37) Intel. 'The Future of RAN is Virtualized and Open'. Accessed: Oct. 09, 2023. [Online].
(38) NVIDIA Developer. 'NVIDIA Aerial'. Accessed: Oct. 09, 2023. [Online].
(39) Arm. 'Microprocessor Cores and Processor Technology – Arm®'. Accessed: Oct. 09, 2023. [Online].
(40) CEVA. 'Wireless Communication | 5G / 4G / LTE Cellular / V2X | CEVA DSP'. Accessed: Oct. 09, 2023. [Online].
(41) AccelerComm. '5G NR Channel Coding Experts | AccelerComm'. Accessed: Oct. 09, 2023. [Online].

Future Trends

129. Future trends and needs for baseband processing and required semiconductors are an excellent source of opportunity for the UK and are likely to be driven by three factors. On the "what":

- New Functionality: New functional requirements for baseband processing are mostly likely to be driven by features and requirements of the roadmap of standard bodies, particularly 3GPP and 6G. This is likely to include new deployment techniques and use cases. Key features being proposed which may provide new baseband processing opportunities include the use of THz bands, "cell-free" operation (Distributed Massive MIMO) and semantic communications. This list is not exhaustive.

130. On the "how", the evolution of baseband implementation is likely to be driven by two trends:

- Exploitation of semiconductor technology advancement: The advance over time of fundamental semiconductor performance, Moore's Law, is well documented. (42) Regardless of any change to function or features, new devices can continue to benefit from these improvements (and any other manufacturing process-related innovations), but each generation of semiconductor technology tends to incur higher and higher NRE costs. (43)
- New Compute Paradigms: All previous generations of digital cellular infrastructure have used some combination of the devices on the list above (2G-5G). With 6G, a move towards "Native-AI" infrastructure, particularly for the Radio Access Network (RAN) portion, is being proposed. (44-45) This could be a highly disruptive event in baseband processing in terms of the algorithmic content, the style of compute architecture required for efficient implementation, the skills required to develop the technology and field proving required.

(42) Wikipedia. Oct. 02, 2023. 'Moore's law'. Accessed: Oct. 09, 2023. [Online].
(43) I. Lankshear, '5G Cellular Infrastructure and the Migration from FPGAs to Custom ASICs', Electronic Design. Accessed: Oct. 09, 2023. [Online].
(44) Ericsson, 'Defining AI native: A key enabler for advanced intelligent telecom networks', Ericsson White Paper BCSS-23:000056 Uen, February 2023.
(45) Nokia Bell Labs , '6G technologies - AI-native air interface - Nokia Bell Labs'. Accessed: Oct. 01, 2023. [Online].

UK Strengths

131. The UK has and has had significant centres of expertise both in the past and currently in the field of wireless baseband processing. A non-exhaustive list of examples is summarised in the table below.

Body	Application	UK-based current and previously active companies (currently active highlighted in Bold)
3GPP	Mobile Cellular Systems	Infrastructure: Picochip (3G/4G DSP/SoC – acquired by Mindspeed, 2012, then on to Intel as part of acquistion of Mindspeed small cell business, 2014) (46-47) Picocom (4G/5G DSP/SoC) (48) AccelerComm (baseband IP) (49) Parallel Wireless UK (RAN products) (50) Handset: Icera (DSP software/SoC/RFIC – acquired Nvidia, 2011) (51) Other: Imec (52)
Bluetooth SIG (Also WiFi, GPS/GNSS etc)	Wireless Connectivity Systems	CSR plc (acquired by Qualcomm, 2015, various wireless assets sold to Samsung Electronics, 2012) (53)

Table 2: Examples of UK commercially exploited expertise in baseband processing and processors (non-exhaustive list)

132. Expertise in baseband processing and development of specialist SoCs is underpinned by the UK's strong tradition in processor and semiconductor design across a broad range of fields primarily centred in the Bristol/Bath area (54) and Cambridge.

(46) 'PicoChip', Wikipedia. Jan. 25, 2021. Accessed: Nov. 27, 2023. [Online].
(47) 'Intel buys Picochip, Avago takes LSI ' clues to the networks of the future', Rethink. Accessed: Nov. 27, 2023. [Online].
(48) 'Home', Picocom. Accessed: Nov. 27, 2023. [Online].
(49) '5G NR Channel Coding Experts | AccelerComm'. Accessed: Nov. 27, 2023. [Online].
(50) 'Parallel Wireless', Parallel Wireless. Accessed: Nov. 27, 2023. [Online].
(51) 'Icera', Wikipedia. Jun. 11, 2023. Accessed: Nov. 27, 2023. [Online].
(52) IMEC. Accessed: Jan. 24, 2024. [Online].
(53) 'CSR plc', Wikipedia. Oct. 25, 2022. Accessed: Nov. 27, 2023. [Online].
(54) Wikipedia. Feb. 26, 2023. 'Silicon Gorge', Accessed: Oct. 09, 2023. [Online].

UK gaps and barriers

133. Examining the three strands identified in the Future Needs section, the following barriers for exploitation by UK industry are apparent:

134. Semiconductor Funding: The semiconductor angle will be treated in full by the Semiconductors EWG but to summarize here: whilst the UK has a strong tradition in semiconductor design, and in both IP and fabless production, the costs of producing multi-core SoCs continue to climb to an average, across all geometries, of $12.2M in 2027. (55) The cost of advanced nodes would typically be somewhat higher than this driving the capital requirements of any business, start-up or established player. The design cycle from a “blank whiteboard” to the first ramp in the commercial deployment of equipment containing a complex SoC for wireless infrastructure can be of the order of 5 years. (56) New innovative entrants will need investors with a depth of pocket and a realistic view of exit timescales.

135. Field testing of advanced capabilities: Both new deployment models (e.g., “cell-free” operation) and new compute/algorithmic approaches (“Native-AI”) are significant departures from the nature of today's networks. To successfully deploy and fully exploit the benefits of these advanced technologies, a deep understanding of their behaviour in a range of real-world deployment scenarios is required. Replicating such scenarios in a lab is very challenging to do in a truly representative manner. Further still – an emerging concern in native-AI RAN is the harmonious operation of AI between different subsystems in the RAN and the interoperability of AI provided by different vendors. Interoperability testing and field trialling of these techniques will be essential to complete the development of products and showcase the capabilities they offer.

136. AI for Wireless Skills: The development of AI solutions to a problem naturally requires a practical understanding and experience in the development and deployment of AI models. However, in baseband processing, especially in mobile wireless networks, the problems to solve require deep understanding of the nature of mobile traffic, signal processing and cellular propagation characteristics. Deep domain insights are crucial to any successful development process in AI and attracting AI specialists to the telecoms industry may prove difficult given the high demand across all fields.

(55) Semico Research, ‘Average Design Cost for Advanced Performance Multicore SoCs to Reach $12.2M by 2027, says Semico Research’. Accessed: Oct. 09, 2023. [Online].
(56) Peter Claydon, ‘The roadmap to 2030’, Small Cell World Summit. 2023. [Online]

Noting the potential technology transition in 6G, reducing the dependency on conventional approaches listed earlier in this section, an effective approach would be to train those with those domain skills how to develop deployable AI solutions. Given their existing skillsets its likely to be easier route to train an experienced RAN baseband processing expert in the ways of AI than an AI expert in how the RAN works. A leading wireless industry player has commented (57) on their success in up-skilling existing wireless systems architects in AI techniques for wireless systems. Further still, given the move to native-AI wireless network implementations, wireless system architects should be highly incentivised to acquire these skills to progress in their careers. See the section on skills and talent.

Recommendations

137. For the baseband processing and semiconductor area the following recommendations are made:

138. Advocate and support the upskilling of the existing base of those with deep baseband processing expertise in the field of AI.

139. Support field trial access to trial innovative new techniques and demonstrate interoperability of AI techniques – for technical readiness levels 5-9 ahead of commercial 6G roll-out (globally not just UK) to allow UK based companies to mature and show-case products (UK operators would also benefit in participating to learn hands-on of new capabilities). This is also essential to continue open RAN momentum into 6G.

140. Create an investment environment conducive to the funding business innovating in semiconductor compute devices for baseband processing in the RAN.

(57) '5G Advanced - Next Gen Mobile Networks and Services - Day 2'. Accessed: Jan. 24, 2024. [Online]. Available: see Session 1: AI/ML in 5G-Advanced (84:00 onwards - Free registration required)

Standards and Intellectual property

State of the art

141. Standards and Intellectual Property, especially patents, are critical to the global wireless ecosystem. Patents provide incentives for researchers and innovators by protecting and rewarding their research and innovation investment. Standards, on the other hand, ensure the interoperability between products so that any equipment, including user devices such as mobile phones, is compatible with networks around the world. International Mobile Telecommunications (IMT) standards such as 3G (IMT-2000), 4G (IMT-Advanced), 5G (IMT-2020), and future 6G (IMT-2030) are key for the development of the global digital connected society. Standardization is strategically important to the telecommunications industry due to the value of scale of the economy, compatibility and interoperability between competing implementations. Interoperability between separate functions, modules and products drives network effects which can be powerful enough to make the standard lock-in for a very long time.

142. Whilst standards aim at the creation of stability and sameness (technical process), standardization itself as an activity is a highly dynamic phenomenon (social process). The dynamical relationships in standards making may be either competitive or cooperative, but they can have both aspects simultaneously. These relationships can be present in the goals of the standard, in the organisational structure of the standards making body or in interaction style of the delegates.

143. At a high level, standards may be either de facto or de jure standards:

- De facto standards emerge through a dominant design or through a custom or convention that has achieved a dominant position. The standardization process is typically restricted in access and constitutes direct participation of consortia or individual companies. This environment may allow fast decisions.
- De jure standards are developed in Standards Developing Organisation (SDOs), based on an open and consensus-oriented process with the option of opposition. This may lead to lengthy decision procedures. Participation and voting rules in de jure standards making are usually clear and transparent.

144. Most of the global telecommunications SDOs, such as ETSI (European Telecommunications Standards Institute), 3GPP (Third Generation Partnership Project), (58) IEEE (Institute of Electrical and Electronics Engineers) and IETF (Internet Engineering Task Force) are de jure SDOs. They usually require that patents that are essential for implementing compliant equipment, known as Standards-Essential-Patents (SEPs), are available to implementors on a fair, reasonable, and non-discriminatory (FRAND) basis. Whilst these SDOs are not involved in the licensing of SEP patents, they have developed policies and practices related to SEP declarations to support the efficient licensing of SEP patents. A smooth licensing environment is essential to the success of a standard. It helps to achieve broad and rapid diffusion of innovation and to give patent holders an adequate return on investment in research and development (R&D). It also gives all users of the standard fair access at a reasonable cost.

145. All generations of existing (2/3/4/5G) and future (6G) mobile telecommunications systems rely on thousands of patented technologies to work. Taking 5G as an example, a rigorous study (59) was recently published with focus on identifying the Top-50 organisations leading the race on 5G SEPs. The study reported that as of July 2023, the number of declared 5G patent families has grown to over 60,000 with about 30,000 patent families granted in Europe or the US, increasing at a rate of about 5,000 patent families annually. The number of 5G patent owners has increased from 32 in 2015 to 131 unique owners in 2023. The study also showed that the top 10 owners control about 76% of all 5G declared patent families, with early indications that these same companies are trying to increase their SEP shares in 6G, the first standards for which are expected to be specified by 3GPP towards 2026-2027. These Top-10 organisations are listed in Figure 1.

Body	Application	State of the art standard
3GPP	Mobile Cellular Systems	5G NR Release 18 (33) (5G Advanced) -> 6G
IEEE	Wireless Connectivity Systems	Wi-Fi 7 (IEEE 802.11be) (34)
Bluetooth SIG	Wireless Connectivity Systems	Bluetooth 5.4 (35)
Connectivity Standards Alliance (CSA)	IoT connectivity	Zigbee PRO 2023 (36)

(58) Note that 3GPP is not formally an SDO in itself, but an informal (though highly influential) partnership of regional SDOs, which transpose 3GPP specifications into formal standards.
(59) LexisNexis, "Who is leading the 5G Race", lexisnexisip.com, 2023, (accessed 2023-11-27)

Rank	Company	HQ	Rank 5G families*	Rank Patent Asset Index 5G Families*	Rank 5G relevant 3GPP contributions
1	Huawei	CN	1	3	1
2	Qualcomm	US	2	1	4
3	Samsung	KR	3	2	5
4	Ericsson	SE	6	6	2
5	Nokia	FI	5	7	3
6	LG Electronics	KR	4	4	8
7	ZTE	CN	7	8	6
8	Oppo	CN	7	12	12
9	NTT	JP	10	13	9
10	InterDigital	US	14	5	15

*Active and granted EPO or USPTO
CN: China; US: United States; KR: Korea; SE: Sweden; FI: Finland; JP: Japan

Figure 2: Ranking of the Top-10 5G SEP family owners

146. Whilst no UK-headquartered company has made it to the top-50 5G SEP family owners, it is noteworthy that several of these top-50 companies, including noticeably 4 in the top-10, have relatively sizeable R&D teams well established in the UK for over 10+ years, and directly contributing to their companies' shares of SEP in 5G and future 6G. These include Finland-headquartered Nokia, US-headquartered Qualcomm, Mavenir and Parallel Wireless, US-headquartered InterDigital, and South Korea-headquartered Samsung. Sweden-headquartered Ericsson has also recently announced the addition of an R&D team in the UK with focus on 6G.

147. Taking Wi-Fi7 as another example, studies (60) showed a similar trend as for 5G and 6G. Figure 3 below shows the top-25 Wi-Fi7 patent owners. Whilst no UK-headquartered company has made it to the top-25 Wi-Fi7 SEP owners, this is noteworthy that several of these companies have relatively sizeable R&D teams well established in the UK for over 10+ years, and directly contributing to their companies' shares of SEP in Wi-Fi7 and future Wi-Fi8 and LiFi via the IEEE 802.11bb standard.

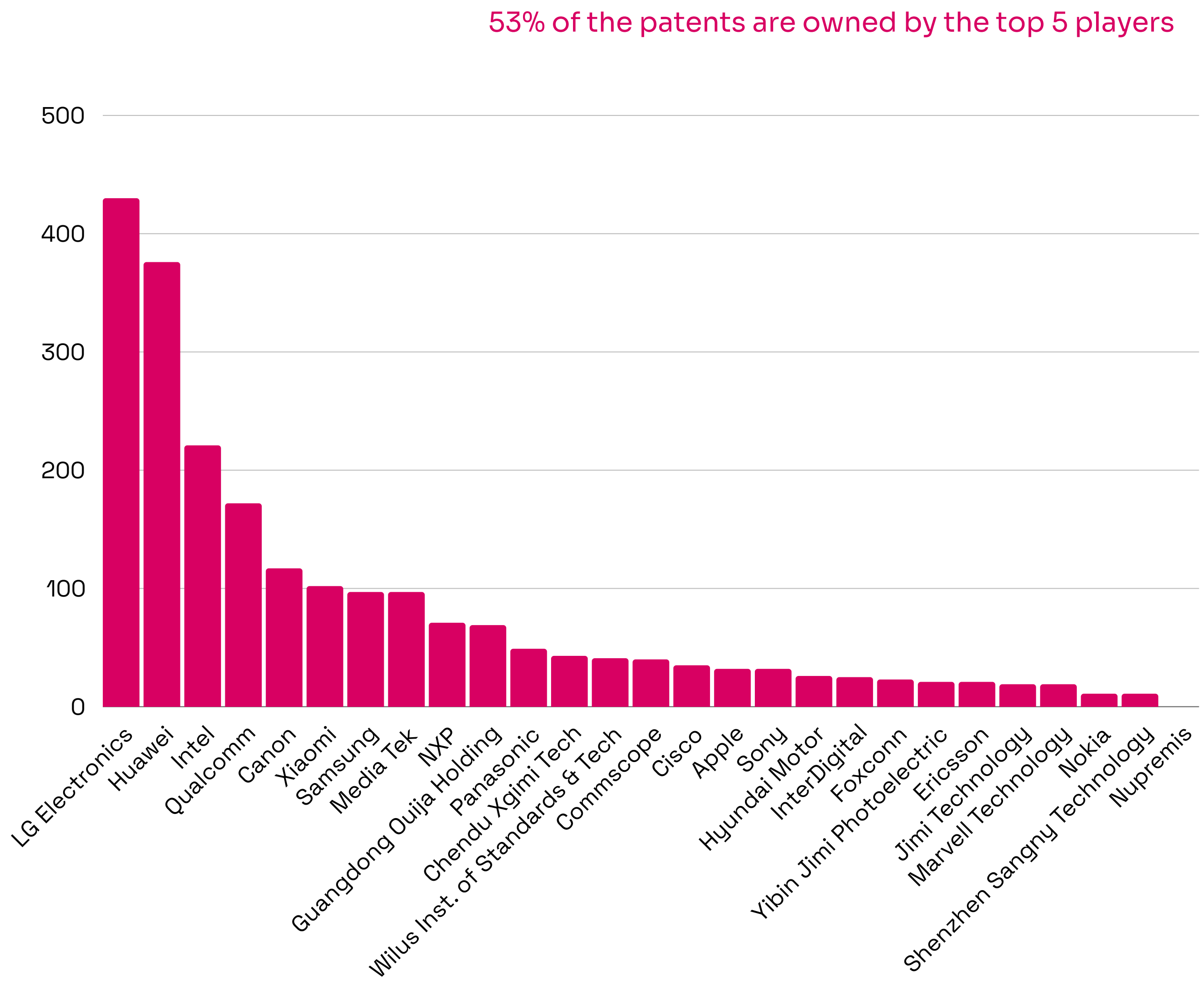

Figure 3: Top-25 Wi-Fi 7 patent family owners

(60) iCUERIOUS, "TECHNOLOGY OVERVIEW REPORT - WI-FI7 (THE FUTURE OF WIRELESS COMMUNICATION)", icuerious.com, 2022, (tried to access 2023-11-27 – this is not a reliable site).

UK Strengths

148. The UK has several strengths that it can build upon to further its impact on the global mobile telecommunications standards.

149. First, the UK has a strong research and innovation ecosystem as outlined starting at paragraph 111). This ecosystem is primarily led by universities with top ranking globally such as the Russell Group of universities. These universities are pioneering foundational research in wireless technology that is surely relevant to the areas of focus identified in international wireless SDOs such as 3GPP. These universities are also providing a pipeline of new talent hired by the research and innovation industry leading in the field of 5G/6G patents and standards.

150. In addition to these universities, the UK is currently home of relatively sizeable R&D sites of several companies leading globally on SEP patents for both Cellular 5G/6G and Wi-Fi 6/7/8 standards, including noticeably five of the top-10 5G SEP owners globally on 5G/6G, namely Qualcomm, Nokia, Ericsson, Samsung, InterDigital. Combined, these UK based R&D sites feature quite a few hundred specialized wireless inventors and standards experts, many hired directly from top UK universities or historical global wireless technology companies with strong basis in the UK such as Marconi, Research-in-Motion (Blackberry), Motorola and Nortel. It is noteworthy that the specialized standards and patents engineering teams for international companies leading in 5G patents and standards are only a fraction (a few hundreds) of their overall R&D teams (several thousands).

151. Furthermore, the UK is strong in consulting firms that partner with the industry leading on 5G and 6G. These include firms such as Accenture, Analysys Mason, Boston Consulting Group, Cambridge Consultants, Capgemini, Deloitte, McKinsey & Co and Real Wireless.

152. Thanks to these British engineers, the UK has been one of the top countries with leadership roles in key international SDOs setting the specification of 5G and future 6G, namely ETSI and 3GPP. At ETSI, the UK is a top country in terms of organisations that are ETSI members, but equally importantly for British engineers holding various leadership roles such as (ex)CTO, ETSI Board, ETSI technical committees and industry specification groups. In 3GPP, (61) several British engineers have been holding top leadership roles (e.g. Chair, Vice-Chair) in various RAN, SA and CT Working Groups. It is also noteworthy that British engineers play an active role in various pre-standards organisations and other (than 3GPP, ETSI) wireless standards which are also key in influencing the wireless standards agenda, such as IEEE, IETF, NGMN (Next Generation Mobile Networks Alliance), GSMA (GSM Association), GSA (Global Mobile Suppliers Association), O-RAN (O-RAN Alliance), TIP (Telecom Infra Project), and Small Cell Forum.

153. Additionally, English, as the default language for setting international standards, is surely a strength for the UK. Strong communication and negotiation skills in English are pre-requisites set by the industry for hiring their new breed of 5G/6G patent and standards engineers. The international diversity in the UK is also an added asset to the English language for UK engineers to establish links with their peers on the international stage in these global SDOs.

UK gaps and barriers

154. The UK scientific research does relatively poorly in terms of creating patents which could lead to UK advantage and economic growth. (62) As the scientific research in the UK is mostly led by universities, these researchers are currently not incentivised to create patents and disseminate these patents into international SDOs. There is also a lack of coordinated research efforts towards attainment of goals on patents and SEPs.

155. In particular, it is challenging for researchers at UK universities to develop a portfolio of patents, owing to the high cost of patent filing and maintenance. As a result of this, universities require a robust business case to be made for each proposed patent application, supported by engagement with industry partners who could license the technology or progress towards the raising of investment for a spin-out company, for example. Specific policies and practices differ substantially between universities. For some UK researchers, this enterprise engagement is appealing, but for others it represents a distraction from their research.

(61) 3rd Generation Project Partnership, "3GPP", 3gpp.org, 2007, (accessed 2023-11-27)
(62) UK Government, "UK Wireless Infrastructure Strategy", gov.uk, 11 April 2023, (accessed 2023-11-27)

As a result of this, the number of UK university researchers engaged with generating patents and the number of patents that they can generate is significantly hampered. Furthermore, patenting the IP that arises from collaborations between universities and industrial partners can be complicated, which can impose a barrier. This may be navigated through the adoption of a suitable collaboration agreement from the Lambert Toolkit for example.

156. Non-academic innovators on the other hand find it extremely challenging to file patents on their own and pursue the dissemination and monetization of their innovations in international SDOs. They are naturally excluded from standards-setting. Participation in these international SDOs requires multiple years of active contribution that is highly demanding in resources, typically not affordable for these small innovators.

157. While there are many UK-based individuals who are contributing to wireless networking standards, the majority of these individuals represent regional offices of organisations that are head-quartered outside of the UK. There are relatively few individuals who represent UK universities and SMEs in attendance at standards organisations. Without the support network, knowledge, mentoring and political weight that individuals representing large organisations benefit from, individuals from UK universities and SMEs face significant challenges when trying to push their innovations into standards. As a result of this, the number and impact of contributors to standards from UK universities and SMEs is limited.

158. In general, it can be observed that influence in 3GPP is beyond the pale of most Europe-based companies apart from the likes of Nokia and Ericsson. UK MNOs are active at plenary level in steering the Work Items but are not so visible in the technical WGs where the IPR is introduced into specifications. To illustrate the scale of the challenge to UK based entities is to consider that e.g. Huawei has 40+ delegates in 3GPP RAN WG1 (Physical Layer), and many other large vendors are also above twenty delegates.

159. Finally, the UK has a relatively low global ranking in terms of patent generation for wireless networking. According to 2021 data provided by the WIPO, UK-based inventors rank 8th in the world for the generation of granted patents in telecommunications, digital communications and basic communications. It may be observed that the granted patents of some of the higher ranking countries are dominated by particular companies, such as Huawei in China, Qualcomm in the USA, Samsung in the Republic of Korea and Ericsson in Sweden. Hence, it may be considered that the UK's global standing in terms of wireless networking patents is hampered by the absence of an equivalent global-scale resident company.

Recommendations

160. It is recommended for the UK to build upon its strengths to fill the existing gaps in turning its world class research and innovation into patents adopted in international standards, which could lead to UK advantage and economic growth. A public-private partnership framework for intellectual property between the UK universities, research institutes, and smaller innovators, on one hand, and the global industry present in the UK and internationally on the other hand, is recommended. Such a framework should aim at ensuring there is a targeted and coordinated research and standards effort in the UK in tandem and close collaboration between the public and private stakeholders towards attainment of certain (e.g. Government) goals on patents and standards impact. This framework should also find the means to incentivize and support the UK researchers and companies to maximize the impact of their work into international standards.

161. More specifically, a UK fund should be created to support UK universities and SMEs in particular to apply for patents and help monetize these patents for example through licensing directly or indirectly (e.g. via patent pools). This would make it easier for researchers to convince UK universities to fund patent applications and increase the number of patents generated. This would also increase the enterprise focus in UK universities and lead to more engagement between universities and industry. Researchers would benefit from being able to make a stronger case to their universities to fund the patenting of their work. They would also benefit from greater impact for their research through their engagement with industry and standards. However, it should be noted that there are significant challenges associated with the monetization of patents, including the long gestation period required to generate a portfolio of granted patents that have significant relevance to emerging standards, as well as to generate licensee income that starts to fund the activity.

INTERNATIONAL EXAMPLE: FRANCE BREVETS

France Brevets was a public investment fund and patent assertion entity established with €100M of funding in 2011 by the French government. Its primary objective was to acquire patents developed across France in strategic technology areas, then license these patents to companies for commercial use. Notable successes were enjoyed by France Brevets in helping French innovators to boost their IP protection and in asserting and licensing patents, including deals with LG, HTC and Qualcomm on near-field communications. France Brevets faced challenges in sourcing valuable French patent portfolios, in monetisation them and with its public sector association, which led to a series of restructurings and changes of focus for the organisation over the years, before it was closed in 2023

162. Furthermore, a network for individuals working for UK universities, SMEs and regional offices of international companies to collaborate in standards organisations should be created. These individuals would benefit from opportunities to network with each other, give and receive mentorship, share knowledge about activity across the standards, as well as to pitch their standards contributions to each other in order to seek support. This would increase the amount and effectiveness of UK contributions to standards, and increase the likelihood of UK patents being accepted into standards. Members of the network (including international companies having UK regional offices) could be given royalty-free or discounted access to the patent pool mentioned above. Members would be under no obligation to contribute their patents to the patent pool. However, in order to retain membership, members would be expected to engage with other members in the standards co-ordination activities. Universities, research institutes and SMEs could contribute their patents to the patent pool. They would retain ownership of the patents, and would receive a portion of the royalties earned from the licensees of the pool. Benefits of this approach may include, increased generation of patents by UK universities, increased generation of spin-outs and licensing deals based on patents from UK universities, increased engagement between UK universities and industry, increased participation in standards by individuals working in the UK (both in universities and in industry), increased effectiveness of this participation and the creation of a critical mass, which can leverage the pockets of excellence around the UK to build a centre of excellence.

163. A selective approach should be taken to determining standards groups which are both impactful and cost-effective to support. Although some standards developing activities are expensive/travel intensive and typically outside the means of SMEs (3GPP), others are more feasible. For example, CEN and CENELEC Working Groups are accessible via the British Standards Institute as assigned experts. IEEE-SA and ETSI are reasonable in membership fees and accessible for SMEs who have the respective competence. ETSI in particular is supportive of virtual presence in meetings. Furthermore, ETSI ISGs such as MEC, SAI, PDL, RIS, THz, and ISAC are relatively low entry barriers for UK universities and SMEs to participate into alongside the industry. We already see a solid UK participation and leadership in these ISGs towards 6G. Finding SDO working groups where an individual's expertise has a larger impact than would be possible in 3GPP could amplify the impact of UK PLC efforts.

Policy and Regulation

State of the art

The UK

164. High level policy in telecoms is the responsibility of Government, with the Department for Science, Innovation and Technology (DSIT) taking the lead. Other Government departments play relevant roles in aspects of telecoms, including Department for Business & Trade, Department for Culture, Media & Sport, Department for Education, Department for Energy Security & Net Zero, Department for Transport, Foreign, Commonwealth & Development Office, HM Treasury, Home Office, and Ministry of Defence.

165. Coincident with DSIT's formation in March 2023, the UK Science and Technology Framework (63) identified Future Telecommunications as one of five critical technologies to making the UK a "science and technology superpower". DSIT has overall policy ownership for all of telecoms and by extension future telecoms, as well as for the Wireless Infrastructure Strategy (64) and the Supply Chain Diversification Strategy. As part of the latter, the UK Government has set an ambition that 35% of UK network traffic should pass through interoperable architectures, i.e. Open RAN, by 2030.

166. This identification signalled a significant change in stance from the position in the early 2000s where the UK moved from being a highly active participant in the development of products and technologies in telecoms space, to becoming an 'intelligent customer' where international companies were expected to provide products to requirements with a consequent reduction in R&D.

167. This identification is very welcome, and it encompasses "all evolutions of infrastructure that carries digitised data". The sectors (agriculture, healthcare, manufacturing, transport) stated in the definition of Future Telecoms look somewhat limited in scope; they may not necessarily have the large scale needed to fully grasp the opportunities for UK-based innovation.

168. 6G is a core part of future telecoms. Nevertheless, it is important to understand that future telecoms would extend beyond 3GPP mobile technologies that constitute a part of IMT-2020; in particular, short range radio, WiFi and Non-Terrestrial Networks provide opportunities for UK innovation.

(63) UK Government, "UK Science and Technology Framework", gov.uk, 6th March 2023, (accessed 2023-11-27)
(64) UK Government, "UK Wireless Infrastructure Strategy", gov.uk, 11 April 2023, (accessed 2023-11-27)

169. This change in stance has led, amongst other early actions, to a desire to (re)build UK capability in future telecommunications, and the creation of UKTIN to foster an ecosystem, including the creation of this white paper.

170. Beyond Government activities, Ofcom is the independent telecommunications regulator in the UK. The Communications Act 2003 (65) states the general duties of Ofcom as:

- to further the interests of citizens in relation to communications matters; and
- to further the interests of consumers in relevant markets, where appropriate by promoting competition.

171. Ofcom must have regard in performing those duties to a number of considerations, including "the desirability of encouraging investment and innovation in relevant markets". However there is no specific duty to stimulate homegrown innovation in the supply of telecommunications technology and any associated benefits have to be balanced, for example, against the need to ensure there is a solid investment case to support the deployment of networks.

172. In addition to its independent domestic role an independent regulator, Ofcom represents the UK position in international regulatory fora such as the CEPT and the ITU.

International Context

173. International spectrum regulation is based on consensus amongst countries and regions. In particular, ITU-R in updating its Radio Regulations works on a multi-year cycle of World Radio Conferences. In the first step, an agenda item has to be proposed and accepted in order to have ITU-R Working Parties address that agenda item during the next study cycle. After this study cycle, a following World Radio Conference then needs to agree on the Recommendations issued from the Working Party studies. It is only after this adoption that Radio Regulations would be updated, and regional regulatory bodies consider to what extent they adopt those changes.

174. The UK contributes towards Radio Regulations typically as a CEPT member state and participates in the Conference Preparatory Group of CEPT.

(65) UK Public General Acts, "Communications Act 2003", legislation.gov.uk, 2003, (accessed 2013-11-27)

176. On the other hand, European Commission decisions are legally binding for EU member states. The UK is no longer involved in EU policy making on regulatory decisions with impact on telecoms, but in many cases those decisions do get introduced into the UK legislation. Whilst the bodies that advice the European Commission on regulatory work, BEREC (66) and RSPG, (67) no longer have UK representation, the UK (or UK based companies) continues to be present in CEPT and ETSI, which constitute the other two corners of the European regulatory triangle (European Commission – CEPT – ESOs).

HARMONISATION / INNOVATION CHALLENGES

Whereas Ofcom showed innovation in acquiring MoD spectrum at 2300-2400 MHz for commercial licences, few CEPT countries allow mobile networks in the same band. Apart from the Baltic states there is little market pull for device support on this band.

177. Current spectrum focus areas for Ofcom include the 3.8-4.2 GHz band for Shared Access Licences and upper 6 GHz band. The former is developed under an EC Mandate in the CEPT, and the latter was one of the key agenda items at WRC'23. Ofcom is promoting the sharing of the upper 6 GHz between Wi-Fi and IMT. (68) Recently, Ofcom consulted on the release of 26 GHz and 40 GHz millimetre wave bands (69) and decided to assign city-wide licences at 26/40 GHz through auction. The lower density areas will be assigned under the Shared Access Licence regime.

Shared use of spectrum

178. The US is leading in the proliferation of shared use of spectrum under CBRS. The ecosystem is already of feasible size for UK companies to get involved in whereas the Shared Access Licence bands in the UK are in their infancy. Germany (70) and Sweden (71) have assigned spectrum for private networks at 3700 MHz band. The work in CEPT under the EC Mandate on 3.8-4.2 GHz local area networks (72) is important as an international activity in finding harmonised approach on shared use of spectrum.

(66) BEREC, "Body of European Regulators for Electronic Communications", berec.europa.eu, 2023, (accessed 2023-11-27)
(67) RSPG, "Radio Spectrum Policy Group", europa.eu, 2023, (accessed 2023-11-27)
(68) Ofcom, "Consultation: Hybrid sharing: enabling both licensed mobile and Wi-Fi users to access the upper 6 GHz band – Ofcom"
(69) UK Ofcom, "Enabling mmWave spectrum for new uses: Statement and consultation on auction design", 8th November 2023, (accessed 2023-11-27)
(70) Germany, "Frequenzen für das Betreiben regionaler und lokaler drahtloser Netze zum Angebot von Telekommunikationsdiensten"
(71) Sweden, "Lokala tillstånd I 3,7 GHz- oct 26 GHz-banden".
(72) RSPG, Radio Spectrum CEPT Mandates "Mandate to CEPT on technical conditions regarding the shared use of the 3.8-4.2 GHz frequency band for terrestrial wireless broadband systems providing local-area network connectivity in the Union", europa.eu, 16th December 2021, (accessed 2023-11-27)

179. In February 2023 Ofcom kicked off a Spectrum Sandboxes activity which follows up from its Spectrum Roadmap. (73) The sandboxes are expected to utilise field trials and the collection of real world data to explore technical solutions to improve the way spectrum is used and shared by different users. The first sandbox focused on the 3.8-4.2 GHz band.

PPDR (Public Protection and Disaster Relief)

180. The requirements of private mobile radio for emergency services and business applications used to be based on analogue radio and specialist systems such as TETRA. In the UK, companies such as Sepura (Cambridge) and Simoco (Derby) develop and sell solutions and products to public sector use, emerging from the former UK company Pye Telecom. While such systems are still in use, they are increasingly being based on 3GPP-focused technology especially LTE based networks. This is indicated by the Home Office decision for future UK emergency services communication to be based on the Emergency Services Network, via shared access to a public LTE mobile network.

181. Nevertheless, for some mission-critical applications existing narrowband land mobile radio systems are likely to continue for the foreseeable future, given their resilience and relative simplicity. The only way 3GPP MCX solutions will achieve full land coverage will be through combination with NTN, which adds another dimension of complexity.It seems more likely that dual TETRA/3GPP devices or similar will become more common to ensure a robust narrowband solution is still there as a fallback.

PMSE (Programme Making and Special Events)

182. UK is a major force in programme making and has been important in European policy making and regulation in this area.

(73) UK Ofcom, "Spectrum roadmap: Delivering Ofcom's Spectrum Management Strategy", Ofcom.org.uk, 20th May 2022, (accessed 2023-11-27)

ITS (Intelligent Traffic Systems)

183. ITS typically has dedicated frequency band to ensure safety of use. The UK follows the European assignment of upper 5 GHz for ITS use. The standards proposed in this space are G5 (IEEE 802.11p) and 3GPP V2X family (LTE-V2X and NR-V2X). This is politically very volatile area and ETSI and CEPT have struggled for a number of years to figure out how the IEEE and 3GPP systems would coexist. G5 has promoters within European industry. In general, 3GPP-based ITS technology is driven by non-European vendors and there is little of that work present in the UK. However, the Government recently made £18.5 million available (74) for supporting UK supply chain for connected and automated mobility and the Centre for Connected and Autonomous Vehicles supports R&D activities. One project under this focuses on High-Performance Imaging Radar.

184. Licence-exempt bands Licence-exempt use spans from Wi-Fi to Short Range Devices. IEEE 802.11 develops RLAN standards which get their seal of approval as Wi-Fi CERTIFIED standards at Wi-Fi Alliance. ETSI TC BRAN develops Harmonised Standards for RLAN, and these cover LTE-LAA and NR-U in addition to Wi-Fi.

185. Similarly to IMT bands, global harmonisation helps the overall licence-exempt ecosystem and the Wi-Fi ecosystem is playing an increasingly important role in spectrum regulation.

186. Many of the current LPWA IoT networks such as LoRa and Sigfox operate on lower licence-exempt frequencies (800 MHz).

187. 57 – 71 GHz is assigned for licence-exempt use in many CEPT countries and it overlaps licence-exempt bands in other markets such as the US and China. Ofcom is extending Shared Access Licences to 26 GHz and 40 GHz bands here in the UK with framework intended to be in place in June 2028.

(74) UK Government: "Supporting sovereign UK supply chain for connected and automated mobility", gov.uk, 5 September 2023, (accessed 2023-11-27)

UK Strengths

Proactive spectrum regulator

190. Ofcom has a long history of being innovative and proactive in radio spectrum regulation. Some examples:

191. TV White Spaces in 2000s where Ofcom was one of the key regulators in promoting the access to broadcast bands where TV receivers would not have been interfered with. This work was the precursor to the use of spectrum databases that are now deployed e.g. in the CBRS band in the USA.

192. Shared Access Licences

Uses	1800 MHz shared spectrum	2300 Mhz shared spectrum	3.8-4.2 GHz	Lower 26 GHz band
Private network (e.g. industry uses)	✓ (narrowband)	✓	✓	✓ indoor)
Mobile coverage (rural)	✓	Certain locations	X	X
Mobile coverage (indoor)	✓	✓	X	✓
Fixed wireless broadband	X	X	✓	Prior authorisations

Figure 4: Shared access licence use cases

193. The framework for Shared Access Licences that Ofcom set up in 2019 has evolved to encompass four frequency bands. The recent statement on mmWave at 26 GHz and 42 GHz also proposed the use of Shared Access Licences.

(75) EENA, "The European Emergency Number Association", eena.org, 2020, (accessed 2023-11-27)

194. The adoption of 3.8-4.2 GHz Shared Access Licences has taken off well as observed in the recent Ofcom Call for Inputs. (76) Norway adopted this UK regulation more or less wholesale in January 2023. These two countries were taken as the starting point in CEPT in its work on the EU Mandate (77) on “technical conditions regarding the shared use of the 3.8-4.2 GHz frequency band for terrestrial wireless broadband systems providing local-area network connectivity”.

195. In addition to Shared Access Licences Ofcom also introduced Local Access Licences in 2019. These licences provide a way for other users to access spectrum which has already been licensed to the UK’s Mobile Network Operators, in locations where an MNO is not using their spectrum. These licences would typically be available in areas where there is no MNO deployment of plans of MNO deployment, such as remote areas and underground mining operations. Ofcom would typically issue a licence for three years.

Presence in European regulation

196. Ofcom has provided numerous chairs to CEPT Working Groups and currently holds the chairs of the ECC, CPG PTA, PT1, WG NaN, SRD/MG (until recently), SE21, SE40; and FM 51 (PMSE) is chaired by BBC. This provides a strong influence on the Conference Preparatory process towards World Radio Conferences.

Radio Equipment Directive

197. The Radio Equipment Directive (78) came into force in 2014, and it links the worlds of standards and policy making. Recently CEN and CENELEC have drafted three new harmonised standards on RED Articles 3.3(d,e,f). These are related to harm to network, privacy and financial risks. UK security experts have been particularly active in this work, which shows the ability for UK to influence European Harmonised standards through established presence in the three European Standards Organisations.

(76) Evolution of the Shared Access Licence Framework: Call for Input
(77) Mandate to CEPT on technical conditions regarding the shared use of the 3.8-4.2 GHz frequency band for terrestrial wireless broadband systems providing local-area network connectivity in the Union
(78) Radio Equipment Directive (RED)

UK gaps and barriers

Spectrum harmonisation

198. Any spectrum bands that are not widely harmonised globally lack handset support. We can see this problem in the 3.8-4.2 GHz band where particularly the upper part above 4000 MHz has little support from UE vendors. The CBRS market proliferation in the USA is improving the supply side squeeze around 3.8 GHz. Nevertheless, particularly from a Neutral Host point of view the small scale of deployments in the UK market at 3.8-4.2 GHz causes difficulties in procuring handsets – particularly as the Ofcom regulations prohibit the use of this band for national commercial use and MNOs have little interest in it. The JOTS operators have approached Ofcom on this but so far the situation is unclear.

199. There is an additional risk in the European Commission trying to forge an independent role in the World Radio Conference preparatory process.

Shared use of spectrum

200. MNOs are typically reluctant towards any kind of shared use so the JOTS initiative in the UK is very welcome, and is world leading in its field. The SAS approach of US CBRS bands is being promoted by those database operators which risks stifling innovation in this field in the UK. ETSI RRS developed specifications some years ago based on the Licenced Shared Access regulation that the CEPT drafted recommendations on; these are now being further developed in joint Working Group between ETSI RRS and WinnForum. WinnForum is another US-based organisation with a very strong CBRS slant (they developed the SAS interfaces, for example).

Access to EU market

201. UK based companies continue to be active in ETSI and develop European Harmonised Standards that can be used for declaration of conformance to bring products to the EU market. In the absence of a European Harmonised Standard, a company can use a notified body to declare conformance with EU regulations. A challenge for a small company in the UK is that there are no longer notified bodies here that have the authority to decide on conformance.

Intellectual property

202. R&D Tax Credits are available for companies to help carry out research in the areas of science and technology. Payments towards filing patents do not qualify for these R&D tax credits, however. Particularly for small businesses the cost of patent filing can be a considerable cost.

Government grants for R&D programmes

203. Typically programmes that allocate funding to Government supported telecoms R&D projects have limited time windows to apply. It is often the case that smaller companies cannot match their R&D schedules to these windows.

Recommendations

204. Ofcom is widely recognised as an innovative and forward-looking regulator in the international scene. It is important to build up on this. In particular, shared use of spectrum is an area where the UK is leading the way (with the US), and international activity there directly supports UK-based companies active in the field. We recommend the UK Government and Ofcom continue their willingness to experiment, provide mechanisms for academia and companies to innovate in radio spectrum use.

205. Many European standards in wireless domain continue to be adopted in the UK. These standards are often based on European Commission mandates. Similarly, some of the regulatory work done at CEPT is based on European Commission mandates. It is crucial that the UK can continue to influence such mandates whilst they are still under preparation. Without RSPG and BEREC membership other avenues such as ETSI become more important. We recommend the UK Government and Ofcom to coordinate with UK-based industry consortia and companies to keep influence channels open towards Brussels.

206. Mobile networks use ITU E.212 numbering (MCC + MNC + IMSI) where the number of MNCs is limited. Recently, there is activity in CEPT based on an earlier ITU-R recommendation to introduce shared use of MNCs and coordination on the use of MCC 999 which is a 'free-for-all' today. The UK should lead in providing access to shared MNCs and better coordinated private network MCCs for private networks and UK neutral host companies.Extend the qualified expenses to R&D Tax Credits to patent filing and pursuit.

207. Adopt the approach used by DASA (Defence and Security Accelerator) where grants are allocated on open calls which are rolling around a theme, without a specific application window.

208. Intelligent Traffic Systems (ITS) proliferation requires a new infrastructure of Road Side Units (RSU) which likely are a very challenging cost for local authorities. Government spending on setting up ITS Infrastructure in the UK will help establish a lead in Connected and Automated Mobility solutions.

Infrastructure and facilities

State of the art

209. To achieve UK ambitions for world-leading capability in research, development and innovation of wireless networking technology, we will also require world-leading facilities and infrastructure to support that capability.

210. Below we summarise some of the key existing UK facilities in the following areas:

- Wireless Development and Testing
- Wireless Research Facilities at research institutions, including:
  - Anechoic Chambers
  - Channel Characterization, Signal Processing and Testing Facilities
  - Component and Device Prototyping and manufacturing
- Network Infrastructure and Technologies
- Next-Generation Technologies
- Satellite Development and Testing

211. While the list provided is indicative of key capabilities, it is necessarily incomplete and we have chosen deliberately to emphasise facilities which relate specifically to the ‘wirelessness’ of wireless networks, expecting that other EWGs will capture the facilities for wider telecommunication activities. We gathered inputs from requests for information to key institutions and in an open call via LinkedIn. We apologise for any major omissions and would welcome inputs on these to include in future updates.

Key Infrastructure and Facilities for Wireless Development and Testing:

212. Precision Development Facility (PDF) at Rutherford Appleton Laboratory (RAL): A vital component of the Science and Technology Facilities Council (STFC), this facility is situated on the Harwell campus in Oxfordshire. It serves as a specialised centre providing precision machining services customised for the progress of sub-millimeter wavelength receiver technology. Functioning under RAL Space's Millimetre Wave Technology Group (MMT), the facility possesses unique capabilities in manufacturing high-precision components. These capabilities extend to a wide range of applications, notably including transceivers for telecommunications.

213. Sonic Lab: A state-of-the-art 5G and 6G research facility , supported by the UK Government and industry partners, with indoor and newly announced outdoor RAN testing facilities. SONIC Labs is a joint programme between Digital Catapult and Ofcom, funded by DSIT as part of their 5G Diversification Strategy. It is an open network laboratory that provides a space for companies to test and develop their Open RAN products and solutions. SONIC Labs is located in London and has access to a range of testbeds and equipment, including a 5G testbed. It also has a team of experts who can provide support and advice to companies. SONIC Labs is open to companies of all sizes, from start-ups to large established businesses. It is also open to companies from all over the world. The goal of SONIC Labs is to help the UK to develop a strong and competitive Open RAN ecosystem. By providing a space for companies to test and develop their Open RAN products and solutions, SONIC Labs is helping to accelerate the adoption of Open RAN in the UK. Here are some of the benefits of using SONIC Labs:

- Access to a range of testbeds and equipment, including a 5G testbed
- Support and advice from a team of experts
- Opportunity to collaborate with other companies in the Open RAN ecosystem
- Help to accelerate the adoption of Open RAN in the UK

- Digital Catapult: A national innovation centre that helps businesses develop and commercialise new digital technologies, including 5G and 6G.
- UKTL: The UK Test Lab for 5G and 6G, a national facility for testing and validating 5G and 6G networks and devices.
- NPL: The National Physical Laboratory, the UK's national measurement institute, which is leading research on 5G and 6G measurement and standards.

Wireless Research Facilities at research institutions

214. UK research institutions offer a broad spectrum of capabilities and facilities to bolster wireless research, covering aspects from characterization and testing to network management and cutting-edge technologies. Presented below are detailed lists of key elements:

Characterization, Testing, and Evaluation Facilities:

215. Anechoic Chambers: The UK hosts numerous anechoic chambers, with the University of Southampton housing the country's largest. These chambers create an environment free of sound reflections, allowing for accurate acoustic measurements and wireless device testing. Below are a few of the prominent facilities:

- University of Southampton:
  - The UK's largest anechoic chamber, measuring 10m x 10m x 6m
  - Features polyurethane foam wedges for near-complete sound absorption.
  - Utilised for diverse research, including acoustic device testing, sound propagation studies, and noise reduction investigations.
- University of Bristol:
  - Unique truncated pyramid-shaped Anechoic Chamber.
  - Minimises reflections and ensures a uniform sound field.
  - Primarily used for specialised research in wireless communications, radar, and sonar applications.
- National Physical Laboratory:
  - High-Frequency Anechoic Chamber designed for testing antennas and radar systems.
  - Frequency range up to 100 GHz with specialised absorbers for high frequencies.
- Db Technology, Cambridge:
  - Specialises in EMC testing and consultancy services.
  - Nearly fully anechoic chamber with ferrite radio frequency-absorbent material.
  - Features include a large remote-control turntable, pneumatic controls for aerial rotation, a remote video monitoring system, and a motorised mast for height-variable measurements.
  - Semi-anechoic chamber dedicated to radiated tests, covering emissions and immunity, with specific measurements on the OATS.
- UCL Research Anechoic Chamber:
  - Incorporates glass-fibre wedges for free-field conditions above 90Hz.
  - Room within a room design with outer walls 330mm thick and an inner room made of metallic acoustic panels on a floating floor.
  - Equipped with a Bruel & Kjaer 2231 Sound Level Meter and Laryngograph.
  - Signals routed to an adjacent control room with a Sony DAT recorder and a PC; includes a prompting system for presenting recording material.
- University of Salford ACOUSTICS Group Anechoic Chamber:
  - Background noise level: -12.4 dBA
  - Working area dimensions: 5.4 × 4.1 × 3.3m
  - Cut-off frequency: 100 Hz

- Queen Mary University of London General Purpose Anechoic Chamber
  - Dimensions: 9m x 3m x 3m
  - Application: Microwave and millimetre-wave anechoic chamber
  - Capabilities: Facilitates radiation characteristic measurements for feeds and millimetre-wave antennas up to 325 GHz
  - Versatility: Allows for far-field antenna pattern measurements using the entire length or simultaneous use of two ranges when divided
  - Features: Houses an NSI three-axis Cartesian near-field scanner for beam pattern measurements and surface-wave studies
  - Additional Area: Partitioned section supports various EM experiments up to 100 GHz
  - Applications in the Partitioned Area: Includes wireless localization, on-body communication system assessments, and measurements of far-field patterns for horn antennas and novel mm-wave antennas developed in research
- The University of Surrey's Institute for Communication Systems' Anechoic Chamber
  - Size and Acoustic Properties: Measuring 10m x 10m x 6m, it is one of the largest anechoic chambers in the UK, equipped with polyurethane foam wedges to absorb sound waves, creating a near-silent environment for controlled testing.
  - Key Features for Comprehensive Testing: The chamber's large size accommodates testing of sizable antennas and devices. It boasts a low reflection coefficient to ensure accurate measurements, a flexible turntable for rotating devices, and fully automated antenna measurement software for efficient data collection.
  - Versatile Applications: The anechoic chamber is utilised for various applications, including antenna testing (for gain, radiation pattern, and impedance), radio testing (transmitter power, receiver sensitivity, and bit error rate), and wireless system testing (coverage, capacity, and interference immunity).

216. Channel Characterization, Signal Processing and Testing Facilities: The various UK universities have advanced signal processing labs and advanced channel characterization facilities like the 5G mmWave

- Queen Mary University of London is a world-leading research group with a strong international reputation for microwave and THz research and hosts many facilities such as Millimetre-wave CATR, NSI planar near-field beam pattern scanner, THz Time Domain Test Bench, NSI-MI Spherical Near-field/Far-field Measurement System. The phi over theta scanner from NSI-MI Series 700S-60 has the capability of a full spherical, phi/theta-360 deg, rotation with a step resolution of 0.01 degrees in both phi and theta rotations.

- Similarly, the University of Bristol's Channel Measurement Chamber is available to simulate real-world radio propagation environments, allowing researchers to study and optimise wireless performance. The facilities include two Keysight F8 RF Channel Emulators, supporting bi-directional RF links with a 120dB dynamic range, supporting up to 16 independent wireless streams with a bandwidth of 160MHz. The An Elastic Optical Network (EON) testbed has network function programmability (NFP) capabilities, allowing the nodes that can be synthesised with programmable optical nodes utilising reconfigurable Bandwidth-Variable Wavelength Selective Switches (BV-WSS). The EON testbed provides a versatile network environment to verify new concepts and ideas. Additionally possesses two channel sounders: a sub-6GHz multi-channel system and a wideband millimetre-wave facility. The sub-6GHz system, a Medav RUSK, offers 120MHz of measurement bandwidth, full remote MIMO operation, AGC, synchronisation, and supports double-directional channel sounding. The millimetre-wave facility utilises a Keysight 12GS/s M8190A Arbitrary Waveform Generator, an MSOS804A Mixed Signal Oscilloscope for waveform detection and capture, and Sivars IQ transceivers for dual-channel up and down conversion in the 60-80GHz bands. A multi-format coherent receiver is developed for accurate detection of advanced modulation format signals, including PM-QPSK, PM-16QAM, etc. Self-developed digital signal processing algorithms provide the offline processing feature with an intuitive interface. A 4-shannel 80Gs/s real-time oscilloscope can receive optical signals up to 400Gbit/s (50Gbaud PM-16QAM). In addition, receiver-side monitoring technologies are continuously developed to provide monitoring functions without the need of extra hardware. In addition, an automatic OSNR vs. BER characterization platform is available for network performance tests. Five spools of 7-core multicore fibre (MCF) are available for Space Division Multiplexing (SDM) research. In addition, a single mode fibre (SMF) based link with more than 500 km of length is provided for transmission and optical network applications, providing an enhanced interconnectivity facility in between different testbeds for large-scale experimentation.
- The University of Surrey's Institute for Communication Systems hosts antennas and digital signal processing lab, which has anechoic chamber, GHz sensing experiment platform, wideband multiple-input and multiple-output channel sounder (PropSound) includes several antenna arrays, supporting up to 54 transmit channels and 32 receive channels at 2GHz and 5GHz bands, software defined mmWave transceiver System. The University's testbed at the 5G/6G Innovation Centre encompasses an area of four square kms within the Surrey campus. It provides a comprehensive 5G infrastructure, comprising elements such as the 4G and 5G core network, mobile edge computing, access networks (including the 4G and 5G radio access network), satellite systems, Wi-Fi, and LoRA.

The university has other testlab facilities, such as a network lab, satellite integrated 5G/6G networking testbed. Labs like the 5G and Future Wireless Network Testbed at the University of Surrey provide a platform for integrating and testing wireless systems, including network function virtualization (NFV) and software-defined networking (SDN) architectures. Research centres like the Centre for Wireless Communication at the University of Edinburgh develop advanced signal processing algorithms for improving wireless communication efficiency and reliability.

217. Component and Device Prototyping and manufacturing

- Facilities like the Precision Development Facility at RAL Space offer expertise in precision machining and prototyping of miniature components for wireless devices.
- The Henry Royce Institute, a world-renowned centre for materials science and engineering, houses cutting-edge fabrication facilities dedicated to wireless and telecom research. These facilities, including the National Graphene Institute at the University of Manchester, provide researchers with comprehensive tools for designing, fabricating, and characterising novel materials and devices.
- The National Graphene Institute boasts 1500 square metres of ISO class 5 and 6 cleanrooms spanning two floors. This diverse nanofabrication facility is dedicated to 2D materials research and the production of "novel" devices that harness the unique properties of graphene and other 2D materials. The facility houses dedicated graphene layer preparation areas for atomic array extraction/alignment, inert environmental processing, and UHV processing, alongside an extensive range of support equipment for nanofabrication processes. The cleanroom facility is equipped with comprehensive "thin film" characterization tools, including high-resolution SEM (scanning electron microscope), HRFIB (High Resolution Focused Ion-Beam), modelling ellipsometry, Raman spectroscopy, large-area atomic force microscopy, UHV scanning probe microscopy, optical spectroscopy, and stress measurement profiling.
- The Advanced Forming Research Centre (AFRC) at the University of Strathclyde is a 5,680-square-metre research laboratory equipped with a diverse range of forming equipment, including presses, furnaces, and testing apparatus. The materials characterization laboratory within AFRC features various equipment for analysing material properties, including tensile testers. Additionally, AFRC's computational modelling suite is equipped with powerful computers capable of simulating forming processes and predicting the properties of formed components.

- The James Watt Nanofabrication Centre (JWNC) at the University of Glasgow hosts comprehensive facilities to support micro- and nanostructure design, fabrication, and characterization. It houses two Class 100 cleanrooms for controlled nanofabrication, a range of patterning tools for precise pattern creation, and deposition and etching tools to create thin films and microstructures with desired properties. Additionally, the JWNC offers metrology tools for material and device characterization, electrical, optical, thermal, and mechanical characterization tools, and specialised equipment and services.

218. Network Infrastructure and Technologies: In terms of core network infrastructure such as cell towers (including macro cells, micro cells, small cells, and femtocells), there are limited test facilities apart from commercial infrastructure from EE(BT Group), O2, Vodafone, Three, BT openreach, Arqiva, Crown castle international, Cellnex Telecom., etc. The three 5G innovation centres (located at University of Surrey, University of Bristol and University of Strathclyde/Glasgow) have some core infrastructure for testing and trials. The antennas design research labs are prominent at more than 20 UK universities. The switching equipments from different vendors for testing purposes in the research labs are procured from different vendors such as Juniper Networks, Cisco Systems, Extreme Networks, Juniper Systems Limited, Aruba Networks, and Arista Networks, EXFO, ZyXEL Communications, CML Microcircuits, Black Box Network Services.

219. The UK has a strong research infrastructure in fibre optics, enabling research on high-speed data transmission and backhaul for wireless networks. The notable universities' group include, University of Southampton's Photonics and optoelectronics, UCL's Optical Network group, Bristol Optical group and EPSRC funded National dark fibre facility (NDFF).

220. Next-Generation Technologies: The UK is at the forefront of 5G/6G RAN/ORAN research, by participating in initiatives like the ORAN Alliance driving the development of open and interoperable RAN architectures.

- The 5G Innovation Centre (5GIC) at the University of Surrey is a world-leading research and development centre focused on accelerating the development and adoption of 5G and next-generation wireless technologies. Established in 2018, the centre brings together academics, researchers, and industry partners to collaborate on innovative 5G solutions for a wide range of applications. The 5GIC's state-of-the-art research facilities, including:
  - 5G RAN testbed: A dedicated 5G RAN testbed for developing and testing 5G RAN technologies.
  - 5G core network testbed: A 5G core network testbed for simulating and evaluating 5G core network concepts.

  - Over-the-air (OTA) test chambers: OTA test chambers for testing wireless devices in a controlled environment.
  - Anechoic chamber: An anechoic chamber for testing antennas and devices in a near-silent environment.
- Similarly, 5 GUK Test Network at the University of Bristol are actively developing and testing 5G radio access network (RAN) technologies, including Massive MIMO and beamforming. The University of Bristol is one of the few centres with capability to collaboratively research and experiment on applications and network elements within a testbed with an End-to-End standalone 5G/B5G service delivery capability, based on O-RAN, multi access technologies like WiFi-7 & LiFi, along with 5G air interface, and the multi access technology RIC research capability. Research focus is on networks of networks, including wireless, optical, satellite, and quantum technologies. Current research activities at University of Bristol on 5G/6G with the source and size of the funding include:
  - REASON: UK funded project £12m
  - Allegro: EU funded project Euro 11m
  - Future communications hub in all-spectrum connectivity £7.8m
  - TITAN - Platform Driving The Ultimate Connectivity £10m
  - JOINER- Joint Infrastructure for Network Research £13m
  - SWAN: Secure Wireless Agile Networks
- University of Bristol testbed has its cloud core network infrastructure at Merchant Venturers Building (MVB) with edge node footprints in Bristol city, UK national nodes through the NDFF network and global connectivity through the Fabric network . See here and here for further details.
- The Scotland 5G Centre (S5GC) is a national initiative established by the Scottish Government to accelerate the adoption and development of 5G technology and its applications across Scotland. Based at the University of Strathclyde and the University of Glasgow, the S5GC serves as a focal point for collaboration and innovation. It brings together industry partners, researchers, and public sector organisations to push the boundaries of 5G technology and its impact across various sectors. Notably, the Scotland 5G Centre has overseen the deployment of over 1,000 5G sites across Scotland, improving coverage and accessibility. Additionally, the Centre has supported more than 100 5G innovation projects, contributing to the development of groundbreaking 5G applications in healthcare, transportation, manufacturing, and other sectors.
- King's College London is at the forefront of fostering ultra-low latency 5G tactile internet advancements with a focus on Internet of Skills applications. The university's 5G Tactile Internet Lab is spearheading groundbreaking 5G co-design initiatives in collaboration with diverse industries, including smart cities, smart transport, performing arts, and healthcare.

- The University of York's ISA communication lab hosts 5G/6G facilities, including ORAN development and testing infrastructure. Additionally, the current research and deployment and testing activities include three DSIT and UKRI projects, with details on the funding source and size included.
  - YO-RAN:UK Funded project: £4.7m
  - REACH: UK Funded project: £3.1m
  - CHEDDAR- Communications Hub for Empowering Distributed Cloud Computing Applications and Research: £11m
- In the private sector, Vodafone has established a private Open RAN lab in Newbury, UK, to address their specific technical and business requirements for deploying Open RAN technology. This lab will focus on end-to-end productization and support of Open RAN network elements within the Vodafone network. Vodafone's goal is to deploy 2,500 Open RAN sites in the UK countryside, and they are actively engaging with other ecosystem players to ensure interoperability and integration with their legacy infrastructure.

221. Key Infrastructure and Facilities for Satellite Development and Testing: The UK's space industry enjoys a robust reputation, underpinned by world-class infrastructure and facilities for satellite development and testing. Here are some notable state-of-the-art facilities:

- Satellite Applications Catapult: The Satellite Applications Catapult is one of the leading institutions in the UK dedicated to advancing satellite technology and applications. It collaborates with academic institutions and industry partners to drive innovation in satellite communication, Earth observation, and navigation.
- Surrey Satellite Technology Limited (SSTL): SSTL is a leading British company specialising in the design, manufacturing, and operation of small satellites. It collaborates with universities and research institutions to develop satellite technologies. Based in Guildford, Surrey, SSTL stands as one of the foremost global satellite manufacturers, having constructed over 400 satellites. Its facilities include a clean room, a test bed, and a launch site, ensuring precision and reliability in satellite manufacturing.
- National Satellite Test Facility (NSTF): The NSTF stands as the United Kingdom's most extensive and all-encompassing satellite testing facility, situated within the STFC RAL Space Laboratory in Oxfordshire. It offers a diverse range of testing capabilities catering to satellites of various sizes, spanning from cubesats to substantial spacecraft. The NSTF's facilities comprise:
  - Spacious vacuum chambers designed for testing within a simulated space environment.
  - Vibration testing facilities aimed at verifying a satellite's ability to endure the challenges of launch.

    - Acoustic testing chambers devoted to assessing noise and vibration levels.
    - Mass properties facilities equipped to measure the precise weight and balance of satellites.
    - Electromagnetic compatibility (EMC) testing facilities ensure that satellites do not interfere with other electronic systems.
- Goonhilly Earth Station Limited: Goonhilly Earth Station is one of the world's largest and most historic satellite ground stations, with a heritage dating back to the 1960s. It is located in Cornwall, UK, and it is used for a variety of purposes, including:
    - Receiving signals from satellites in geostationary orbit
    - Transmitting signals to satellites in low Earth orbit
    - Providing backhaul for telecommunications networks
    - Supporting scientific research projects
- National Space Propulsion Test Facility (NSPTF): Located in Westcott, Buckinghamshire, the NSPTF specialises in testing state-of-the-art engines for small satellites. It houses a comprehensive range of facilities, including a rocket engine test stand, vacuum chamber, and cryogenic facility.
- Harwell Space Cluster: Situated in Harwell, Oxfordshire, this cluster hosts several world-leading space companies such as Airbus Defence and Space, OneWeb, and the UK Space Agency. The facilities encompass laboratories, clean rooms, and test beds, fostering cutting-edge advancements in the space industry.
- RAL Space: A division of the Science and Technology Facilities Council (STFC) and situated in Harwell, Oxfordshire, RAL Space is a research institute equipped with state-of-the-art facilities. These facilities include laboratories, clean rooms, and test beds, playing a crucial role in advancing space research and development through the Satellite Test and Validation Centre (STVC) and the National Satellite Test Facility (NSTF).
- Airbus Stevenage: The Stevenage site of Airbus Defence and Space in Hertfordshire serves as a central hub for the design and manufacturing of Telecommunications, Scientific, Earth Observation, and Meteorology Satellites. Additionally, the site is involved in the development of Planetary Surface Robotics, spacecraft structures, propulsion systems, mechanisms, and antennas. With an Assembly, Integration, and Test (AIT) workforce exceeding 300 highly qualified employees, the Stevenage site operates within cutting-edge facilities, making it one of the best-equipped locations in the space industry for development, assembly, testing, and production.

- The Space Geodesy Facility (SGF): The SGF is part of the Natural Environment Research Council (NERC), supports geodetic and geophysical research with a state-of-the-art satellite laser ranging (SLR) system and Global Navigation Satellite Systems (GPS and GLONASS) receivers at Herstmonceux, East Sussex. Funded in collaboration with the Ministry of Defence, SGF is integral to global SLR and GNSS networks, registered with the International Laser Ranging Service (ILRS) and the International GNSS Service (IGS). SGF GNSS data is archived through BIGF, contributing to EUREF and serving real-time navigational applications. The site also hosts an Ordnance Survey GeoNet GNSS reference station and a British Geological Survey broadband seismometer. It is home to a number of state-of-the-art satellite tracking, atmospheric sensing, and gravity measuring sensors.
- Sutherland Spaceport: Formerly known as Space Hub Sutherland, received planning permission in November 2020. In November 2022, it was announced that Orbex would build and operate the facility. This spaceport, situated in Sutherland, Scotland, is designed for space missions and satellite launches.
- The Centre for Space Technologies (CST): It is a cutting-edge development centre at Spaceport Cornwall, providing launch companies with essential operational facilities, landside offices, labs, and available land for development on the business park. It delivers groundbreaking, secure, and dedicated access to space, prioritising responsibility. Moreover, the CST serves as a central hub for individuals, businesses, and innovative ideas to come together, fostering the development of new products and services that contribute to the improvement of life on Earth.
- Arqiva Satellite Ground stations: Arqiva, a British telecommunications company, oversees numerous ground stations across the UK, providing services in satellite communication and broadcasting. Their activities encompass the distribution of television and radio broadcasts via satellite.
- Royal Air Force Menwith Hill: RAF Menwith Hill, situated near Harrogate in North Yorkshire, England, is a Royal Air Force station offering communications and intelligence support services to the United Kingdom and the United States. The facility comprises an extensive satellite ground station and serves as a hub for communications intercept and missile warning operations. Often touted as the largest electronic monitoring station globally, RAF Menwith Hill plays a critical role in surveillance and intelligence activities.
- Clyde Space: Headquartered in Glasgow, Scotland, specialises in the development of small and micro spacecraft systems. The company offers testing services for both satellite components and systems.

- ESA Sites: The European Space Agency (ESA) has several facilities in the UK, including the ESA's ECSAT (European Centre for Space Applications and Telecommunications) facility in Harwell, which focuses on satellite telecommunications research and development.
- University Research in Satellite Communications: Several UK universities have research programs and facilities dedicated to satellite communication. University of Surrey Internationally recognised for satellite technology and wireless communication research, particularly at the Surrey Space Centre, which focuses on space-related projects, including small satellite technology and communication. Cranfield University is actively engaged in research related to communication, Positioning, Navigation, and Timing (PNT), with a focus on satellite communication. University of Strathclyde is known for its research in space systems and satellite communication, with the Strathclyde Space Institute conducting research in satellite technology and applications. University of Edinburgh specialises in satellite navigation and positioning systems, including advanced algorithms and systems for satellite-based communication. University of Glasgow conducts research in satellite communication, particularly in the context of space technology and applications. University of Southampton has a strong research emphasis on wireless communication, including satellite communication, and has made notable contributions to wireless technology development. Imperial College London engaged in various areas of wireless communication research, including satellite communication, as part of its broader engineering and technology programs. University of York hosts High Altitude Platforms (HAP) research, with a low-altitude testbed for conducting trials related to wireless communications, angle-dependent propagation measurements, physical layer network coding, environmental monitoring for smart cities, tree health assessment, and urban pollution monitoring. Cranfield University is actively involved in vertical integration research for communication and Positioning, Navigation, and Timing (PNT), driven by the need for increased accuracy in future autonomous systems. They prioritise maintaining sovereign capabilities, particularly in defence, for greater resilience. Collaborations with Spirent and Inmarsat aim to integrate multi-constellation Global Navigation Satellite System (GNSS) capabilities into various autonomous vehicles and aerial platforms. The NTC Timing Innovation Nodes, based at institutions like Surrey, Cranfield, and Strathclyde, offer atomic-level accuracy to ensure precise synchronisation among autonomous systems and sensors. There are also future plans to achieve even higher optical precision. Additionally, the utilisation of UK sovereign terrestrial 5G networks serves as a backup to Global Navigation Satellite System (GNSS), strengthening the reliability of the system.

222. In conclusion, the UK's telecommunications and space sectors possess cutting-edge infrastructure and facilities, showcasing the nation's commitment to technological advancement and its pivotal role on the global stage.

Strengths

223. The overarching observation from the list above is that the UK possesses a robust infrastructure base for general connectivity use cases, with a primary focus on throughput (MBB) and ongoing efforts to expand coverage through specific initiatives mentioned above. The UK stands at the forefront of antenna research, boasting world-class facilities across various institutions. Notable centres and research groups include the Surrey 5G/6G Innovation Centre, the Antenna and Electromagnetics (EM) group at the University of Queen Mary in London, research facilities at Loughborough University, the University of Canterbury, University College London (UCL), Imperial College London, and institutions in Glasgow, Leeds, and York. These entities significantly contribute to advancing antenna technology and electromagnetic research on a global scale.

224. Channel characterisation, testing, and evaluation facilities, including a dozen anechoic chambers, are concentrated around a few selective academic institutions. There is a need to diversify these facilities across other institutions. In terms of Satellite Communication, numerous research programs and facilities in the UK specifically focus on satellite communication. Forefront institutions include the Surrey 5G/6G Innovation Centre, National Satellite Test Facility, National Space Propulsion Test Facility (NSPTF), Harwell Space Cluster, European Space Agency (ESA) Sites, RAL Space, Surrey Satellite Technology Limited (SSTL), and the University of York's ISA-HAP lab. The Government's recent funding in different initiatives strengthens wireless and telecommunication research and development, facilitating all skills and expertise to build infrastructure and facilities in wireless and telecommunications.

Gaps

225. There is a growing Data Centre base that can support a new era of distributed architecture and underpin advanced wireless technologies. However, many data centres are owned by big US companies, necessitating an intervention to support how to strengthen telecom infrastructure in terms of cloud computing.

226. The UK stands out in fundamental security research, with institutions such as Royal Holloway, University of London, Newcastle, Oxford, Imperial, York, Lancaster, Glasgow, Edinburgh, and Queen's University Belfast being global leaders in security research. However, the emphasis on applied security research in wireless communication and telecommunication has not gained recognition as appealing in the past decade, resulting in the expansion of gaps in system interoperability.

Recommendations

227. To bridge the security and diverse interoperable system gaps, universities and research institutions need to collaborate with industry partners on real system deployment to share knowledge, develop practical solutions, and address real-world security challenges.

228. While 5G test and trial projects offered valuable insights and in-depth exploration of 5G technology use cases and integration, a significant limitation is that many of these trials operated for a limited time, lacking the provision of sustained testing facilities. Therefore, there is a demand for permanent testbeds, akin to SONIC labs.

229. The necessity for a security-focused Edge/Cloud interface underscores the importance of extensive academic research covering a spectrum from low to high Technology Readiness Levels (TRL) in the security perspective of 5G/6G networks. This involves bringing together interdisciplinary expertise for a comprehensive approach.

230. A comprehensive testbed is required to facilitate full end-to-end technology integration, encompassing the 5G/6G communication environment, incorporating both satellite and terrestrial components. The diversity and distribution of funding to support expertise and facilities at different academic institutions are needed.

Skills and Talent

State of the art

231. Skills are a vital component of the UK wireless industry. Without a sufficiently broad and deep education, knowledge and experience of relevant wireless domains, all other activities are constrained. Skills are required both for designing, building and operating UK networks, as well as for conducting R&D&I activities. This section concentrates on the latter, but it should be remembered that given a finite skilled wireless workforce, the former will be the essential first call to maintain public connectivity.

232. The need for and availability of UK wireless skills has varied over time aligned with the UK industry's changing emphasis. At the start of the Wireless Networking Era in the early 20th century, optical communications - which required knowledge of Aldis (signal) Lamps - and radiocommunications – requiring transceiver and antenna knowledge including knowledge of the ionosphere for Long-Wave transmission - shared Morse Code skills with cable telegraphy.

233. As public Wireless Networks started to proliferate in the 1970s and 1980s they skipped the electro-mechanical equipment seen in earlier terrestrial telephony and adopted a common electronic technology base. For the next 30 years common SW, HW and Systems level design, integration, test and maintenance skill for wireless and fixed networking went hand-in-hand, with ATM and later IP skills required for transmission. Substantial UK firms thrived: for example Pye Telecom, later Philips Telecom, grew from 20 staff in 1945 to more than 2500 UK employees in 1985 and 3500 worldwide in 1997, responsible for 85% of the UK radio communications market and 60% of all radio communications exports from the UK.

234. In the 1990s the UK possessed a robust Telecoms Industry R&D. While there were broadly covering both fixed and wireless networking, the systems requirements were already so large that the multi-national players (e.g. Nokia in Farnborough, Ericsson in Guildford and Nortel in Harlow) shared development resources across many countries, with offices and cities developing particular products or subsystems rather than develop the entire solution.

235. They were attracted to the UK to join native scale R&D such as BT, Plessey, Racal and Marconi. They grew strongly during the 90s (for example Nokia had multiple offices in Farnborough, notably opening up Southwood for 1500 R&D employees in 2001 and Ericsson grew from 3 Guildford Business Park to add the larger #4/Midleton Gate and Stoke Mills (plus Manufacturing at Scunthorpe customer sales offices) to over 3000 employees at their peak upon, they had already closed 1200 manufacturing jobs by the time they added Marconi (Coventry) in 2006. Similarly it's likely that Nortel reached their UK R&D peak (8300 employees) in 2000, with over 2000 layoffs in 2001.

236. Motorola in Basingstoke employed thousands of staff. Motorola in Swindon hit a peak in 1999 employing 3000 staff, but declined to just 500 when it closed in 2010 having lost market share to Nokia, Ericsson and Huawei.

237. It should be noted that the above pools cover both network infrastructure and mobile devices (Nokia, Motorola, (Sony)Ericsson and Blackberry/RIM and latterly Samsung). The mobile devices staff buttressed the network infrastructure staff, and shared corporate support structures. The total absence of these – Samsung excluded – created a significant viability issue for the telecoms infrastructure teams when they were eradicated, with the remaining staff being mainly sales and administration based.

238. The economic downturn of 2008-9 saw many companies close or pare back their UK R&D teams. Ericsson axed the final UK R&D teams in Ansty (Coventry) at a cost of 700 jobs in November 2009. Nortel ceased trading in 2009 with Ericsson and Avaya picking up more products and IP than personnel. These were their last in the UK and ultimately replaced by R&D nodes in low-cost countries.

239. Today, air Interface, channel coding and ever improving RF transceiver HW remain Wireless specific skills. But more recently the infrastructure – starting in the Core and BSS domains – has evolved to General Purpose, and with the emergence of RAN Intelligent Controller and Open vRAN, Cloud, Data Centre, SW Application and AI skills are now transferrable into/out of Wireless Networking. Recruitment and retention of skilled staff now has a larger pool in these domains, along with IP backbone and networking. Assembling this infrastructure into profitable public, private and Neutral Host networks are also undervalued areas of business and product expertise, in addition to technical skills.

240. In several senses, Hub-and-Spoke has become the delivery model of Wireless Network R&D. From a corporate perspective, the Hub tends to be in the home market or a perceived low-cost market such as Bangalore, and the spokes are in areas of collaborative expertise. From a UK perspective this practically means Cambridge and Bristol from a cross-industry perspective, and Ipswich from a BT Adastral Park Centre of Gravity angle. These hub companies feed off each other from a collaborative and labour mobility perspective. They also encourage inward investment, such as SoftBank's acquisition of ARM Ltd in 2016, and Samsung Cambridge Solution Centre established in 2012.

241. However they are not large enough to generate their own spokes, and there are many disciplines where the UK has little or no industrial R&D capability.

242. While we have referenced BT Adastral Park as a strength above, it should be noted that in addition to vendors consolidation we have also seen CSP consolidation. With each CSP generally funding their own R&D, there has been a corresponding reduction in R&D activities. When 2 MNOs became 4 in 1993, we had BT and Mercury Communications as major Telcos, with Telewest and CableTel already leading the Cable market. With UK Mobile CAGR of 50% in 1998 to 2000 drove a market of 5 Mobile Operators (One2One, Orange, Vodafone, Cellnet and 3). Today we have just 4 major CSPs in the UK, VMO2, BT, Vodafone and 3. Of these, Vodafone is noted for having centralised its R&I into Centres of Excellence – with the UK splitting the Radio Centre of Excellence with Spain.

243. In summary, companies possessed self-sustaining pools of skilled labour, fed both from a parental hub, and from similar pools of talent from local and regional competitors.

UK strengths

244. Collaborative endeavours have long been UK telecoms strengths. Since the 5G Tests and Trials Programmes, universities and industry have also been encouraged to collaborate, with a core of Kings College London, University of Surrey 5GIC, University of Bristol engaging with all tier 1 RAN vendors for material and knowledge sharing.

245. The UK possesses both significant lobbying capability and a pragmatism to turn ideas into reality. Where gaps and blockages exist, new ways have been sought to resolve them, with the UK having a significant Neutral Host Infrastructure industry, delivering to reduce costs and providing deployment skills to the MNOs.

246. These skills are not purely technical skills in RF, power and engineering, they are also skills of brokering compromise, negotiation and reconciliation around common causes. They are financial skills, bridging the gap between capacity and coverage demands, and the financial limitations preventing those demands being met. Skillful presentation of the longer term business case has allowed access to long term pension funding, and successful delivery of the long term yields demanded has funded growth and diversification rather than contraction and consolidation.

UK gaps and barriers

247. While academia maintains a broad R&D base, since the 2008-9 downturn has seen a general contraction, and there are few signs of the existence of any lighthouses let alone potential unicorns.

248. Indeed there are many under- or non-represented areas. At CWTEC 23, it was notable that – with the context that 92% of internet traffic, including 73% of Smartphone traffic – was transported over Wi-Fi, there was only a single delegate who would be associated with Wi-Fi.

249. With upwards of 25000 skilled employees leaving the Telecoms Industry in the past 15 years, many found that they had transferrable skills which enabled them to prosper in adjacent industries such as IT and Energy Networks. Perhaps the key to bringing them back into Telecoms is to identify and actively target adjacent industries where those skills reside.

250. A key element here is that – without a high profile and without apparent celebrated success – telecoms struggles to attract talent. But without attracting those skilled employees and benefitting from their inputs, how do we create the profile and success path to attract and retain them? Similarly the industry employment is now dominated by smaller companies, which both lack the investment capabilities and patience to nurture large numbers of young talent, which was a feature of the prior generation. Such was the size of the graduate intake of the likes of BT, that in the 1990s they felt that they did not need to actively attract talent, simply to assess and select the cream of applicants. We can no longer afford such complacency.

Recommendations

Build on UK strengths and support industry

251. Celebrate small industrial kernels/hubs such as those fostered by major vendors should be and assist in raising them to sustainable levels. Examples are those in NEC, Nokia Samsung, Intel, Sony and Qualcomm should be celebrated and raised to sustainable levels beyond the typical 10/20 to 50 R&I pools which used to be an order of magnitude – or more – higher.

252. Encourage industry to re-ignite sponsorship and graduate programmes which have been rarely seen by the current and coming generation.

253. Focus upon areas where UK strengths exist and deliver high value such as systems integration and infrastructure provision and wider services (not only products). Make the most of UK innovations such as the only MNO-approved shared architecture in Europe in the form of JOTS – Boldyn has chosen to HQ in the UK along with Cellnex, Freshwave, WIG and Shared Access. Recognise the importance of AI as an increasingly important skill in wireless networking especially in the disaggregated RAN (the AI Expert Working Group provides detailed recommendations in this area).

254. Develop shorter term wins, e.g. in commercial, capital and real-estate services, which are in strong demand by Communication Service Providers and are very well represented in the UK and has a shorter path to success.

255. Bring high value IT techniques into the wireless networking curriculum.

INTERNATIONAL EXAMPLE: DEVELOPMENT OF COMPUTER SCIENCE IN INDIA

The inception of Computer Science education in India traces back to the Department of Computer Science and Engineering at the Indian Institute of Technology Kanpur (IIT Kanpur), marking a pioneering milestone in August 1963. At that time, the initiation of computer education was revolutionary, with the department employing an IBM 1620 system—an innovation not yet widespread, even in many North American and European universities.

In the subsequent decades, particularly during the 1990s, a shift occurred as a few private institutions embarked on offering computer science and engineering degree courses. These endeavours aimed to address the escalating demands of multinational companies, both internationally and within the Indian landscape. The industry recognised the potential in the burgeoning pool of talent and resources. As the momentum in the field progressed favourably, the surge in demand for education in computer science became more than an academic pursuit—it transformed into a lucrative business opportunity. Private engineering colleges emerged, catering to the educational needs of the burgeoning young population. However, this expansion came with its own set of challenges.

In the pursuit of meeting the escalating demand, some private institutes compromised on the quality of education provided. This compromise, unfortunately, resulted in producing a significant number of graduates who were not adequately equipped for the job market, leading to a pool of unemployable individuals. This experience underscores a valuable lesson: while seizing global opportunities is crucial, it is equally imperative to uphold and prioritise strengths and maintain a commitment to quality education.

This historical trajectory serves as a reminder to future educational ventures, emphasising the significance of balancing expansion with a steadfast commitment to delivering high-quality education, ensuring that graduates are well-prepared and competitive in the dynamic professional landscape.

Promote, attract and retain

256. Recognise the importance of AI as an increasingly important skill in wireless networking especially in the disaggregated RAN.

257. Develop strong, diverse role models to attract new talent and promote telecoms as an attractive career and as a sector bringing wider public value.

258. Incentivise industry training schemes, e.g. by offering credits to smaller companies.

259. Learn lessons from adjacent sectors to attract a more diverse talent pool, particularly before the older cohort is not available for skills transfer and mentoring. Engage the older generation, retaining them as consultants in order to use and transfer their talents beyond their expected retirements and loss of expertise.

260. Reduce the additional costs of postgraduate via targeted repayments of student loans, and visa costs for example.

261. Set out clear options for telecom career pathways so that school leadership and careers advisors benefit from an applied appreciation of the roles available, including differences between direct industry entry, apprenticeships and postgraduate research.

Adoption / Translation

State of the art

262. The Research & Innovation section highlighted the strong UK capability in early technology readiness levels, specifically the research domain of TRLs 1-4, and opportunities to further strengthen and coordinate this capability. However to gain value from these innovations, it is necessary to increase TRLs beyond 4, covering prototyping, product development, market introduction, scaling up for product manufacturing and commercialisation and support. These require very different skills and incentives. As noted in the Research & Innovation section. The UK has a relatively poor record in scaling up from start ups, suggesting the adoption phase in the lifecycle needs particular attention.

263. It is partly push and partly pull when making a case for adoption. Without a clear eventual business case for innovation - intellectual and/or commercial – adoption will not succeed, whatever the technical merits of the new innovation. Taking cell-free massive MIMO as an example: the push from the inventor would be the potential for significant increase in spectrum efficiency; the pull would be a belief by the operators that this increase is affordable and ultimately reduces operational expenditure and increases profit. Connecting these pull and push factors will be critical to UK success.

UK strengths

264. As already described in the Research & Innovation section, the UK university sector has significant strengths in wireless telecommunications and while the record of producing spin out companies could be better, there are examples of good practice. UK R&D&I achievements are highly regarded and many new companies are formed each year to exploit them. These could be start-ups originating in academic institutions, expansions of existing small or medium businesses, or new business units established by large companies. Some examples are listed in paragraph 121).

265. The recent independent review of university spin outs, (79) whose recommendations to further accelerate relevant university policies have been accepted by Government provide a good overview of the sector.

266. Support for business-led innovation from the likes of Innovate UK provides a wider range of near-market opportunities.

(79) DSIT, Independent review of university spin-out companies, November 2023.

UK gaps and barriers

267. The UK investment industry and UK private investors have their own priorities that may conflict with the directions that founders want to take. It is also said that they are more risk-averse than elsewhere.

268. Targeted UK Government interventions support R&D&I for continuing development of know-how, prototypes and IPR but they are not investment or ongoing operational risk sharing.

269. The scale of Government interventions needs to be carefully considered to ensure effectiveness.

270. Advancing beyond TRL 4 involves a multitude of new challenges. Many are faced by any business but some would be critical for adoption in the wireless telecommunications ecosystem specifically:

- Standardisation can unlock adoption but is costly and uncertain. It was discussed earlier.
- The UK is 2% of the global market. Exploitation in the UK would not give companies very much in return on investment., making access to global customers essential. SONIC Labs has worked strenuously to attract participation by UK resident companies with some success, but the pool of contributing small companies is narrow. Meanwhile larger vendors may not be ready to test in open network labs.
- Taking the mission to other marketplaces requires significant expertise and is a big task for small companies. One approach is to join industry forums, which often attract a mix of large and small companies, and do innovative work that is then taken up by larger organisations. The impactful UK founding of Small Cell Forum is a positive example. The USA and Canada have similar cultures so would be a good choice and setting up a local company is necessary – it is also cheap.
- A reference customer is essential, as is a path to real commercial deployment, beyond the common resource-intensivetrial phase. This shares the costs of initial entry at low risk to the partner.

271. Investors in a young SME will have an exit strategy. It may be acquisition by another company, which is subject to Government oversight. (80) It may be an IPO. Sometimes, maybe less often, the founders will want to move on and be bought out. In some cases it could be premature: the company price may be "only" £50M, (IPOs will be much higher), and it could have many years of independent life.

(80) UK Government, "National Security and Investment Act: the 17 types of notifiable acquisitions", 15 November 2021.

TELCO ADOPTION EXPERIENCES

Deploying into telcos is tough. The usual route goes via their R&D organisation, who will seek to prove the innovation out functionally. It might take a year or more to get through this phase. As you crest that hill and expect to start deployment, you find another behind it, where the operational teams test it again, focusing on reliability, availability, manageability, impact on existing network KPIs and so on. If they're willing to start this process it's actually a good sign, but it will take another year and more before you get to volume. Is it any wonder that most SME innovations run out of oxygen before they get to revenue?

There's no magic formula, but superb code quality, a receptive customer, irrepressible stamina and an aligned partner are a good start. ip.access was fortunate in riding the wave of residential femtocells and finding a great scale partner in Cisco who were used to selling into AT&T. It meant that we got very quickly into a deployment cycle - testing in the lab, friendly users, small markets, regions and finally nationwide. Even so it was multi-year journey. But in the end we shipped 2m radios through AT&T. It can be done.

272. Academics focus on creating impact on knowledge and society. As an example, the numbers of citations from other academics is a measure of impact, but may not correlate well with opportunities for marketplace adoption. It can be used to leverage funding for further research. Both contribute to excellence which is measured by the Research Excellence Framework (REF) review for each university and the outcome of the REF determines the funding the university receives. The REF needs to be evolved to ensure incentives for commercialisation are fully represented in the assessment.

273. Research can be many years ahead of market and it is expensive to keep research alive, so universities prefer to provide expertise to industry once research on a particular subject has finished. It works both ways: industry will know where to find academic partners with the expertise they need and will seek them out.

274. The way academic research is done is not country specific and it is common to find international teams. These also attract industry support from significant leading international companies. EPSRC accepts letters of support only from companies established in the UK and there are not many of these. The Haldane principle, (81) reflected in UK law, rightly means only researchers evaluate research proposals, but this limits how specifically Government can direct research to align with policy priorities.

(81) Haldane Principle, Wikipedia, retrieved 29/11/23

275. Innovate UK is more focussed on companies but basic research tends to lose out and some of its programmes are too small for fundamental study. As a result, academics leave for US or work on "smaller" projects. A range of different models for building value from IP out of universities has to be considered appropriate to the circumstances.

Recommendations

276. The recommendations of the UK Government Wireless Infrastructure Strategy, and its Open RAN Principles, should be used to frame interventions that encourage adoption of new innovations, extending current programmes.

277. The constraints placed upon dual use of results funded by civil research programmes may benefit from review. This could encourage innovation in other areas.

278. Open RAN should be fully embraced as an opportunity for good, applied (high TRL) R&D as there are a good range of companies in the UK with relevant skills and ORAN should increase the opportunity to concentrate on a single element vs an end to end system. Also, it is more AI and software dependent so easier to grow than hardware dominant companies. This could be built on for 6G.

279. Greater alignment between university research and facilities and industry could be assisted by "spin-in" companies, which conduct engineering development and testing in the universities and those universities should also have engineers dedicated to mentoring, testing and support of those companies, independent from their own research. Some universities already apply such a model but this could be more consistently applied as an example of best practice.

280. The Government aspiration for UK involvement in 6G are welcome, but imply very near-term action on supporting companies to intersect with 6G standardisation and launch timescales. needs to decide what the UK wants from 6G. Does it want resilience/sustainability in deployment or to be a supplier of systems? It needs to define the UK's role in the 6G ecosystem like DSTL has done for defence.

281. There should be incentives for universities based on implementation and impact dependent on financial output. A national funding pool to top up university funds for research would help.

282. There is a need and opportunity for UK network operators and deployers to play a bigger role in ensuring a pull-through of UK innovation into UK networks, bringing operator benefits of early innovation and innovators benefits of a credible lighthouse deployment. One approach would be to grant operators credits in the form of tax credits or direct funding for qualifying adoption of UK-born technology into their commercial networks.

283. Given the challenges of addressing public mobile markets, we should fully explore and support the potential for adoption routes via adjacent sectors such private, local and short range wireless networks for special applications, defence sector, IoT, Fixed Wireless Access, and special applications such as railways which are already more diverse and may offer faster and less restricted opportunities for adoption.

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